CHAPTER 1

SURFACE OBSERVATION ELEMENTS

INTRODUCTION

In this chapter, we give you an overview of Surface Weather Observations and provide references for observation procedures. We also discuss some of the important values that weather observers calculate from observed data. These values include both physiological indicators and aircraft performance indicators. Physiological indicators are values that help estimate the effects of weather on the human body, and aircraft performance indicators are values that allow aviators to assess the effects of weather on aircraft.

CONDUCTING OBSERVATIONS

LEARNING OBJECTIVES: Identify measurement systems and time standards used while conducting surface weather observations. Recognize the general order in which elements are routinely observed.

Throughout the Navy and Marine Corps, Aerographer's Mates, Quartermasters, and Marine Corps weather observers use similar techniques and procedures to determine the current weather conditions. Accurate and timely submission of environmental observations are basic to the development of oceanographic and meteorological forecasts and tactical indices used in support of fleet operations. The methods used aboard ship differ slightly from those used at shore stations. In this section, we discuss procedures used both aboard ship and ashore.

Some weather elements are observed by using different criteria, depending on the recording format and reporting code used. As of July 1996, all U.S. Navy weather activities have adopted the Aviation Routine Weather Report (METAR) and the Aviation Selected Special Weather Report (SPECI) codes for weather observation procedures. The criteria for these codes are covered in detail in chapter 3 of this module.

The criteria for U.S. Navy surface aviation weather observations ashore are contained in Surface *METAR Observations User's Manual*, NAVMETOC-COMINST 3141.2. There are minor differences in observation criteria between U.S. shore stations and activities located outside of the continental United States (OCONUS). These differences are highlighted in the manual. *United States Navy Manual For Ship's Surface Weather Observations*, NAVMETOC-COMINST 3144.1, is used for shipboard weather observations. Except when necessary, we will not repeat information covered in those manuals, but will refer you to the manual.

Before discussing the procedures or methods used to observe weather elements, let's review some basics about observing and measuring the elements.

MEASUREMENT SYSTEMS

In the mid-1970's, the United States began switching to the metric system for weights and measures. In the field of military meteorology and oceanography, it is common to measure an element by using units from the old system and then converting the measurement to the metric system. Because of this, weather observers should be well versed in both systems and be able to convert units of length, volume, temperature, pressure, and mass. Appendix II of this module contains tables and conversion factors to convert from one system to another. Weather observers make temperature conversions most frequently.

The three temperature scales used are the *Fahrenheit*, *Celsius*, and *Kelvin* scales. The United States and several other countries still use the Fahrenheit scale, which fixes the freezing point of water at 32°F and the boiling point at 212°F. Most of the world uses the Celsius scale, which fixes the freezing point of water at 0°C and the boiling point at 100°C. In meteorology and oceanography, both temperature scales are used, with frequent conversions between the two. Conversions may be made by using a conversion table or by using the following formulas:

$$F = \frac{9}{5}C + 32$$

or

$$C = \frac{5}{9}(F - 32)$$

where F is degrees Fahrenheit, and C is degrees Celsius.

Many calculations in meteorology and oceanography use the Kelvin, or Absolute, temperature scale. A *kelvin* is exactly equal to a Celsius degree in scale, but the starting point of measurement on the Kelvin scale (0 kelvin) is *absolute zero,* or -273.16°C. That is the temperature at which, theoretically, all molecular motion would stop. Water freezes on the Kelvin scale at 273.16 K and boils at 373.16 K. Conversions may be easily made between the Kelvin and the Celsius scales by addition or subtraction using the following formulas:

$$C = K - 273.16$$

or

$$K = C + 273.16,$$

where K is kelvin and C is Celsius degrees.

TIME STANDARDS

Though the hour, minute, and second convention is universally used in keeping time, various time zones are also used. In North America, eastern standard time (EST), central standard time (CST), mountain standard time (MST), and Pacific standard time (PST) are used. Standard time zones generally cover strips of the globe, extending north and south parallel to the longitude lines. Each time zone covers about 15° longitude centered on 0° longitude, with all longitudes evenly devisable by 15. Time zone boundaries that cross land masses have been adjusted by local agreement, and often zig-zag.

Standard time zones for the world are provided in Appendix III. Throughout most of the world, standard time is 1 hour earlier for each time zone to the west and 1 hour later for each time zone to the east. A list of countries, provinces, and states, with their local standard time departure from the 0° longitude standard zone is provided in the *Nautical Almanac,* published each year by the U.S. Naval Observatory. When standard time is used, it is referred to as *local standard time* (LST) or by a standard zone designation, such as Eastern Standard Time (EST) or Ppacific Sstandard Time (PST).

Daylight savings time or *summer time* is the convention adopted by most regions in North America. On the first Sunday in April at 0200, the clocks are set ahead 1 hour. On the last Sunday in October at 0200, they are set back 1 hour. During the summer, time in these regions is called *daylight time;* for example, Eastern Daylight Time (EDT) or Pacific Daylight Time (PDT). Other regions of the world have also adopted this practice.

Another measurement of time sometimes used is local mean time (LMT). *Local mean time* is time measured in 24-hour days relative to the movement of the sun. When the sun is highest in the sky, local mean time is 1200 noon. Within a time zone, local mean time may be off standard time by up to several hours. Local mean time changes by 4 minutes for every degree of longitude.

To prevent confusion between the different zones and types of time, meteorological and oceanographic records, charts, and reports use *Coordinated Universal Time* (UTC). UTC time is kept by using the 24-hour clock. UTC is the local mean time at the Royal Greenwich Observatory in East Sussex, England, at 0° longitude. This time is the same all over the world, regardless of local time conventions. All times in UTC are suffixed with a Z for identification. Because of this, UTC time is sometimes referred to as "Zulu Time." The term *Coordinated Universal Time* and the abbreviation *UTC,* by international agreement, have replaced the older term *Greenwich mean time* and the older abbreviation *GMT.*

ORDER OF OBSERVATION

Surface weather observations are completed and transmitted every hour. The various weather elements are actually observed from 5 to 15 minutes before the hour, for routine observations. The time to begin monitoring the elements should be adjusted as the observer gains speed and experience.

As a general rule, first observe the elements from outside the weather office, and then from the equipment inside the office. Pressure elements and those elements changing quickly should be observed last. Even when automatic observation equipment is used, these general rules apply. Most of the necessary observation data will come from equipment located within the office spaces, but outside measurements, such as cloud type and visibility, should be done first.

Although many observation records and reporting codes are in use, the formats have many elements in common. For example, all surface weather observations include data for state-of-the-sky, visibility, and temperature. Some observation formats require additional data, such as sea condition, seawater temperature, and sea ice conditions. The following sections cover the various data types and the methods used to obtain the data. These data types are not arranged in any particular code format, but are generally arranged in observation order.

REVIEW QUESTIONS

Q1. Which two manuals contain detailed instructions regarding the Navy's surface weather observation program?

Q2. What are the three temperature scales in use today?

Q3. Each time zone covers approximately how many degrees of *longitude?*

Q4. What does the abbreviation UTC mean?

Q5. What observation element should be observed last?

SKY CONDITION

LEARNING OBJECTIVES: Define sky condition and state-of-the-sky. Describe cloud form, cloud genera, cloud species, and cloud variety. Identify the 10 cloud forms and their characteristics. Identify significant supplemental cloud features. Define orographic clouds. Explain cloud layer coverage and total sky coverage. Define cloud ceiling and explain how cloud layer height and ceiling height are measured.

As an observer, your interpretation of the sky condition may determine whether a pilot should fly under instrument flight rules (IFR) or visual flight rules (VFR). In some circumstances, your judgment of sky conditions might even prevent a pilot from getting off the ground. Sky condition reports also reflect developing weather conditions; these reports help predict weather over the next several days.

The term *sky condition* includes all cloud parameters estimated or measured by weather observers. *State-of-the-sky* is a specific term that equates to one of the 27 internationally recognized sky states. These 27 states-of-the-sky are represented by code numbers that identify the type of cloud or combinations of clouds present in the sky, and the changes in the clouds over the past few hours. Refer to Appendix IV, WMO codes 0513, 0515, and 0509.

The following sections discuss the identifying features of cloud types. Both NAVMETOCCOMINST 3141.2 and NAVMETOCCOMINST 3144.1 have detailed descriptions of the 27 states-of-the-sky. Two other manuals useful in cloud identification are the *International Cloud Atlas*, WMO Publication 407, and the full-color edition of *Cloud Types For Observers*, Her Majesty's Meteorological Office Publication 716. Posters and charts are also available from the National Weather Service.

CLOUD IDENTIFICATION SCHEME

Clouds may be identified by using very general terms or very specific names. We can classify cloud identification terms from the most general to the most specific as cloud form, cloud genus, cloud species, and cloud variety. Some clouds also prominent supplementary features that are considered either odd or significant enough to be identified with a specific name.

How specific must the observer be in identifying clouds? In the METAR/SPECI code, the observer is not usually required to identify the clouds by name; only the amount of sky covered by clouds in the various cloud layers is recorded and encoded. However, certain cloud genera and supplementary features are considered significant enough to report as Remarks. In the Land and Ship Synoptic codes, the observer must identify the proper cloud genera, species, and variety in order to select the proper state-of-the-sky code.

The following information on cloud identification is presented to help you understand the various reportable cloud "types."

Cloud Forms

There are three different general cloud forms: cumuliform, stratiform, and cirriform. Cumuliform clouds are puffy, with distinct elements or cells. The puffy appearance of these clouds is caused by moist air rising within the cloud cell. Stratiform clouds develop in uniform layers and present a smoother appearance. Cirriform clouds are the thin, wispy, hairlike clouds.

The primary factor that determines cloud form is the stability of the air. *Unstable* air tends to rise on its *own. Stable* air tends to remain at the same level in the atmosphere. And *conditionally unstable* air will retain its level until some force provides initial lift, and then it will continue to rise on its own.

Cumuliform clouds form because moist, conditionally unstable air is initially forced upward by some lifting mechanism, and becomes unstable. The moist, unstable air cools gradually as it rises, reaches saturation, and condenses to form a visible cloud at a certain level in the atmosphere. The continued addition of moist air maintains the cloud base at that certain

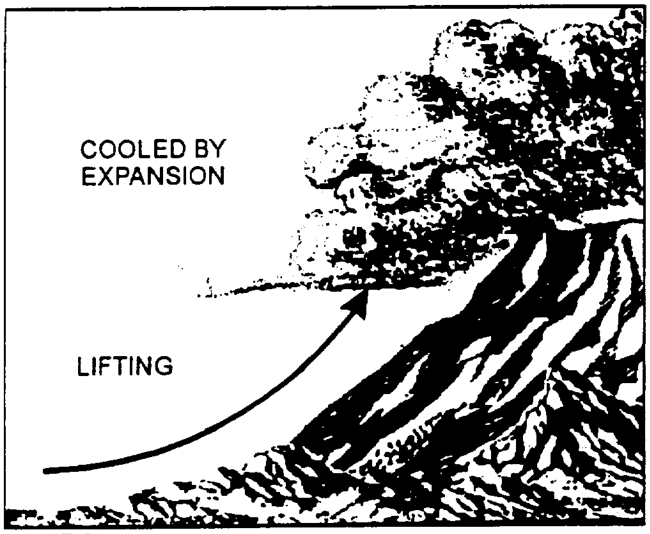

Figure 1-1.—Orographic lift.

height, but the saturated air within the cloud continues to rise, forming the puffy, cumuliform buildups.

Stratiform clouds may form where stable air is brought to saturation by either the addition of moisture or by cooling the air. Most stratiform clouds, however, form when a layer of stable air is forced upward by a lifting mechanism. The entire layer cools as it is lifted, reaches saturation, and forms a cloud layer.

There are four processes that cool the air by lifting the air mass: mechanical lift, convective lift, convergence, and vorticity.

Mechanical lift is a process by which a physical barrier forces air aloft. The barrier may be a sloping plain, a rising coastline, or a mountain. Those land barriers cause a type of mechanical lift called *orographic* lift (fig. 1-1). The barrier may also be air masses of different density; for instance, when fast-moving, warm air overrides the slower moving, cooler air in a warm front, or when fast-moving, cold air forces slower moving warm air aloft in a cold front. Frontal barriers cause a type of mechanical lift known as *frontal lift* (figs. 1-2 and 1-3). *Turbulent lift* is mechanical lift caused by friction between the earth's surface and the air moving above it or between adjacent layers of air in which wind speed (rig. 1-4) or direction is different. Turbulent lift appears to be the key factor in the development of cloud layers with both stratiform and cumuliform characteristics at all levels in the atmosphere.

Convective lift is a process that occurs when cool air is heated from the surface and rises (fig. 1-5). Convective lift is the key factor in cumuliform cloud development within an air mass.

Convergence occurs when windflow at a particular level forces air to "pile up" in a general area, which creates a lifting action. For instance, where straight-line winds of higher speed decrease, more air is transported into an area than is carried away, and a mass of air builds up vertically. This is known as *speed convergence.* Alternatively, *directional convergence* occurs when winds of different directions come together and merge at a certain location. Convergence plays a key role in cumuliform cloud development in the tropical regions.

The last lifting mechanism is *vorticity.* Vorticity is the rotational motion of molecules in the atmosphere,

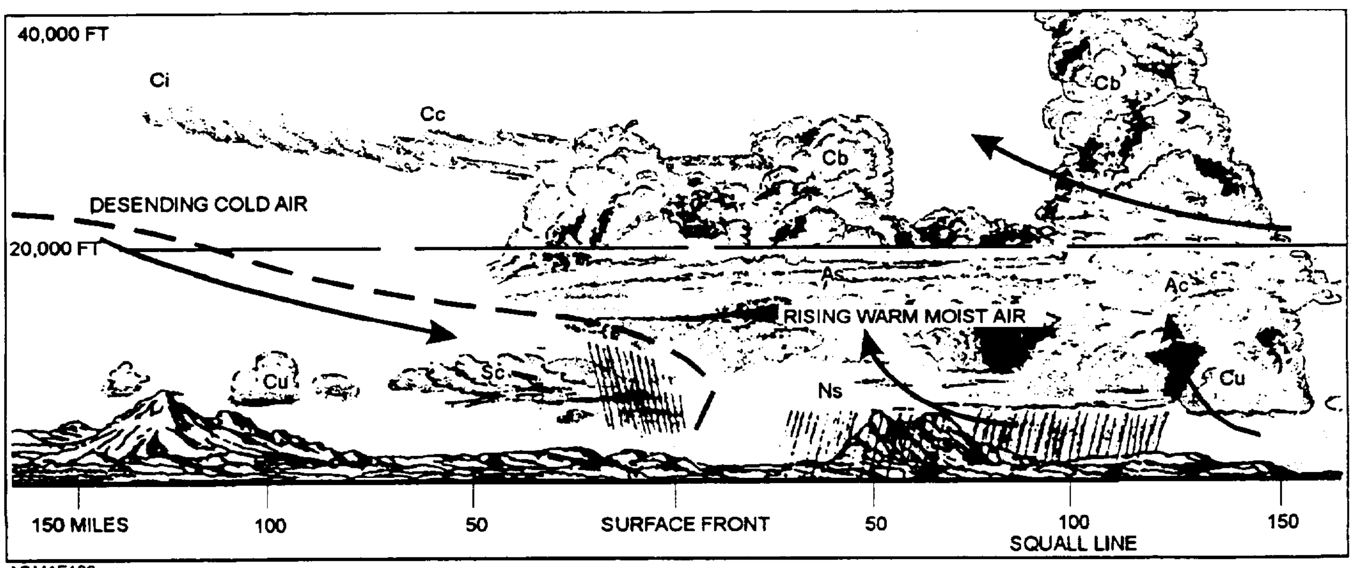

Figure 1-2.—Frontal lift—conditionally unstable air causing cumuliform cloud development along a cold front.

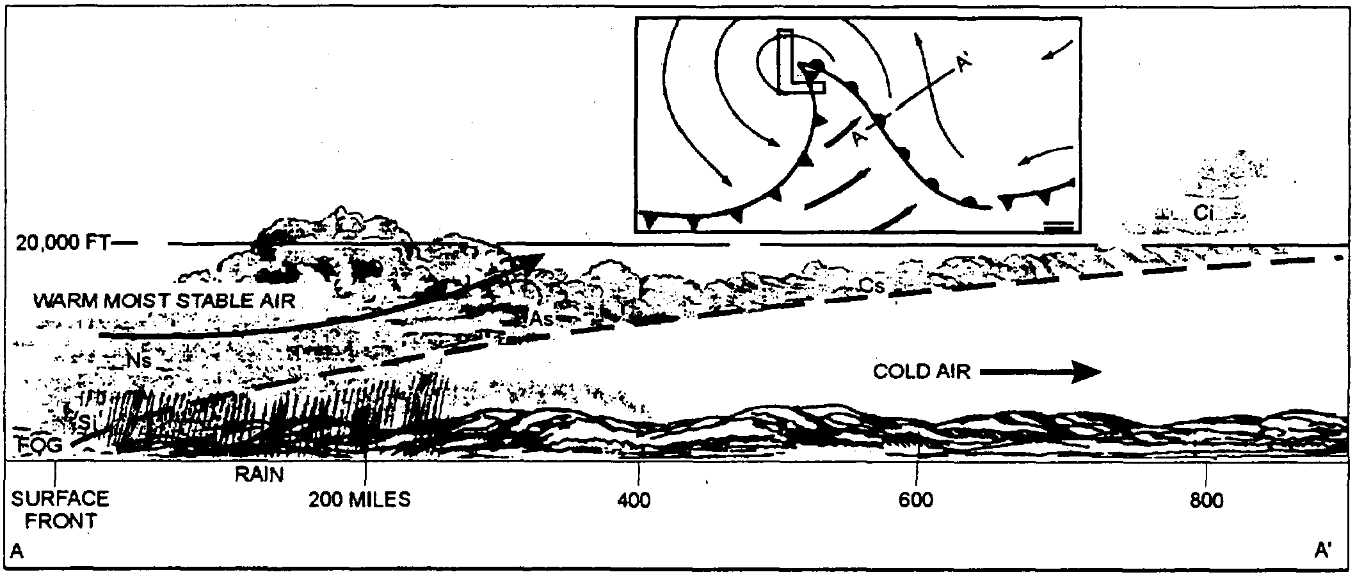

Figure 1-3.—Frontal lift-stable air causing stratiform cloud development along a warm front.

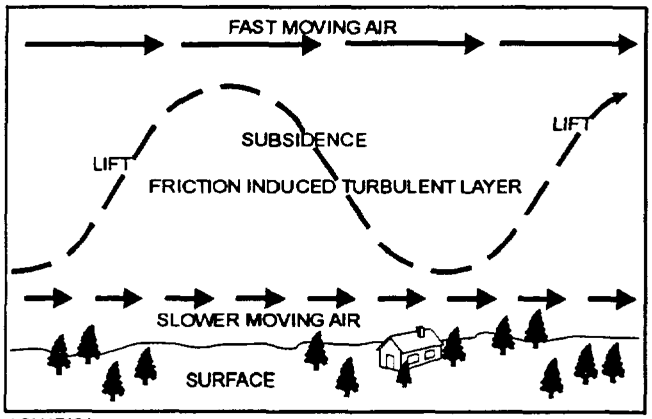

Figure 1-4.—Turbulent lift.

caused by the spinning of the earth and the path of each molecule through the atmosphere. Although the theory is complex, the net result is that air following a cyclonically curved path through the atmosphere tends to rise, while air following an anticyclonically curved path tends to subside. Vorticity is the leading cause of most middle- and high-level, nonfrontal cloudiness.

Air may become saturated without being lifted. At night, air may cool by radiation of heat in a process known as *radiational cooling.* Warm, moist air may move over a cooler surface, such as a cool body of land, and cool to saturation by conduction. *Conduction* is the transfer of heat energy through contact. Finally, air may also be brought to saturation by the addition of moisture

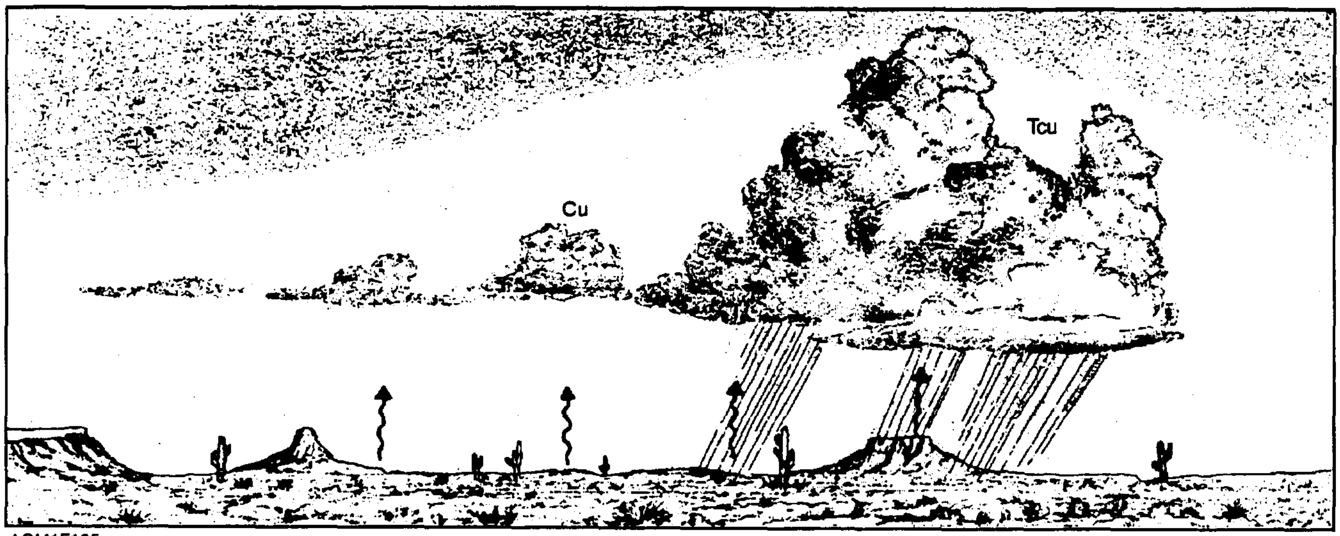

Figure 1-5.—Convective lift.

to the air mass through evaporation. Moisture may evaporate into an air mass from precipitation falling through the air mass and by evaporation from bodies of water. These processes generally are only significant in cloud and fog formation within several hundred feet of the earth's surface.

You will study these cloud formation mechanisms in detail in the later training modules.

Cloud Genera

Clouds are further identified with more specific names that are commonly referred to as cloud type, but are more accurately termed *cloud genera*. The basis for the cloud genera identification is the level at which the cloud forms, as well as the way the cloud formed.

Cloud Etage

With respect to clouds, the atmosphere is broken down into three layers or *etages*. In the middle latitudes or temperate region, the low-etage is from the surface to 6,500 feet; the mid-etage, from 6,500 feet to 23,000 feet; and the high-etage, from 16,500 feet up to near 45,000 feet (fig. 1-6). The limits of the etages are generally lower in the polar regions (mid-etage from 6,500 to 13,000 feet and high-etage from 10,000 to 25,000 feet), and higher in the tropics (mid-etage from

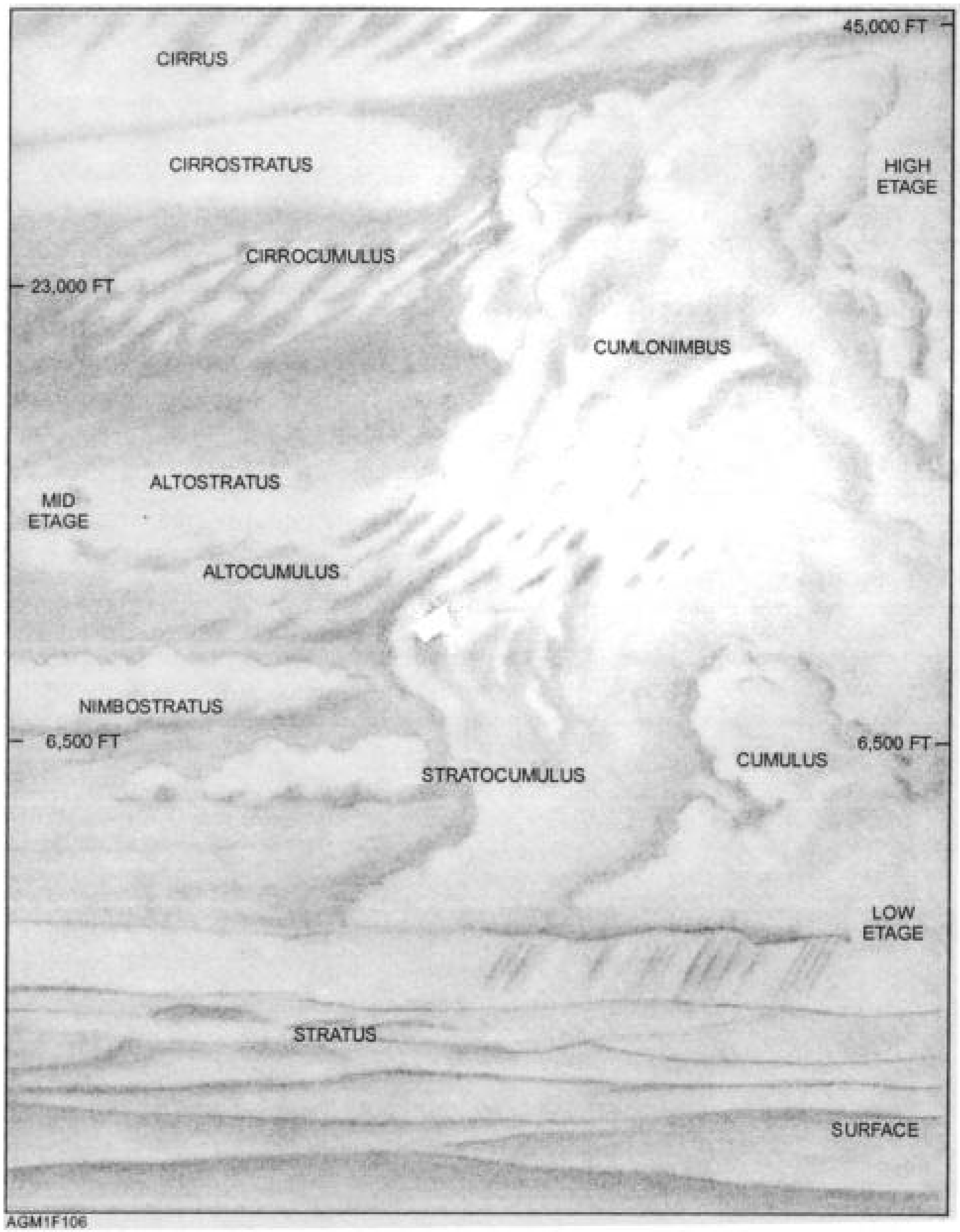

Figure 1-6.—Temperate Region cloud genera—cloud forms in the three etages.

Table 1-1.—WMO Cloud Classification by Cloud Etnge, Form, Genus, Species, and Variety

ETAGE	FORM	GENUS	SPECIES	VARIETY
LOW-ETAGE	Cumulifrom	cumulus	humilis mediocris congestus fractus	
		cumulonim bus	capillatus calvus	
	Stratiform	stratocumulus	floccus castellanus stratiformis lenticularis	opacus translucidus undulatus radiatus perlucidus
		stratus	nebulosus fractus	opacus translucidus undulatus
MID-ETAGE		nimbostratus		
		altostratus		opacus translucidus undulatus radiatus duplicatus
	Cumuliform	altocumulus	castellanus floccus stratiformis lenticularis	opacus translucidus undulatus radiatus perlucidus duplicatus lacunosus
HIGH-ETAGE	Cirriform	cirrus	uncinus spissatus floccus castellanus	radiatus duplicatus intortus vertebratus
	Stratiform	cirrostratus	nebulosus fibratus	duplicatus
	Cumuliform	cirrocumulus	stratiformis floccus castellanus lenticularis	undulatus duplicatus lacunosus

6,500 to 25,000 feet and high-etage from 20,000 to 60,000 feet).

The low-etage cloud genera may be cumuliform, such as the cumulus or cumulonimbus (identified by their size and extent of development); stratiform, such as the stratus; or have mixed characteristics, such as the stratocumulus. The mid-etage cloud genera are mostly identified with the prefix *alto.* The mid-etage contains the cumuliform clouds, such as altocumulus, and the stratiform clouds, such as altostratus and nimbostratus. The high-etage cloud genera contain the prefix *cirro.* Cumuliform clouds in this etage are called cirrocumulus, while stratiform clouds are called cirrostratus. Another form of cloud found only in the high-etage is the cirriform clouds that are the normally thin, wispy, or hairlike ice-crystal clouds that can be defined as neither cumuliform nor stratiform, but are simply called cirrus clouds.

Cloud Species

Besides the identification of clouds by genera, most cloud forms may be further identified by *cloud species.* The species identifies the size, shape, or form of the elements within a cloud layer. Table 1-1 lists the cloud etages, cloud genera, cloud species, and cloud varieties used to identify clouds. To improve your understanding of the many cloud types, be sure to locate the specific classification of each cloud in table 1-1 during the following discussion.

Cloud Variety

In the 27 *states-of-the-sky*, many of the differences between different "cloud-states" are not based solely on genera, but on a combination of the genera, species, and variety. Cloud *variety* identifies the specific appearance of the arrangement of elements within a cloud layer, the thickness of the layer, or the presence of multiple layers. The nine different cloud varieties are used to further identify cloud species by specific appearance. The variety name is appended after the species name to further identify a cloud. An example is "stratus nebulosus opaqus," which is a low-etage stratiform cloud (genus, stratus) without distinct features (species, nebulosus) but dense enough to obscure the sun (variety, opaqus). State-of-the-sky codes usually do not name the cloud variety, but give a description of the dominant cloud genus, species, and variety. The nine varieties in table 1-1 are defined as follows:

- **Opaqus:** A sheet, layer, or patch of clouds the greater part of which is sufficiently dense to obscure the sun or moon. Opaqus is used to modify low- and mid-etage stratiform cloud layers, particularly those of the species stratiformis. It is not used with the species cirrus spissatus, since spissatus is inherently opaque.

- **Perlucidus:** Clouds of the genus alto- or stratocumulus, usually of the species stratiformis, in which the distinct spaces between the cloud elements allow blue sky, the sun, moon, stars, or higher clouds to be clearly seen.

- **Translucidus:** A sheet, layer, or patch of clouds the greater part of which is sufficiently translucent to reveal the position of the sun or moon. The term is used to modify low- and mid-etage stratiform cloud layers, particularly those of the species stratiformis. It is not used with any of the high-etage cloud names, since these clouds are inherently translucent.

- **Duplicatus:** Two or more sheets, layers, or patches of cloud of similar type at different levels in the atmosphere, commonly overlapping. This situation is usually associated with the species fibratus, uncinus, stratiformis, and lenticularis.

- **Undulatus:** Elements or cells in a sheet, layer, or patch of clouds arranged in parallel rows and forming a wavelike pattern similar to swell waves in the ocean. The popular names for these cloud patterns are "billow clouds," "wind row clouds," and "wave clouds." This wavelike pattern is principally found in the genera cirrocumulus, altocumulus, altostratus, and stratocumulus, but is rarely associated with stratus. When distinct rows and columns are apparent in the pattern of cloud elements in a single layer, the term *bi-undulatus* may be used.

- **Radiatus:** A cloud pattern, similar to undulatus, in which cloud elements in the rows are merged together so that parallel bands of clouds are formed. Due to the effect of perspective, these straight parallel bands seem to merge together near the horizon. The popular name for this cloud pattern is Abraham's Tree. This pattern is frequently associated with the genera cirrus, altocumulus, altostratus, and stratocumulus, and usually associated with the species stratiformis.

- **Lacunosus:** A cloud pattern in which the rounded holes between the clouds form a honeycomb or netlike pattern is the dominant feature. The clouds may be equated to the wax of a honeycomb or the cord in a net. This pattern is associated with the genera cirrocumulus and altocumulus, and is usually used to further define the species stratiformis, castellanus, or floccus.

- **Intortus:** Associated only with the genus cirrus, this term is used when the cirrus fibers or filaments are entangled, curved, bent and irregular, or form a zig-zag pattern.

- **Vertebratus:** Associated mainly with the genus cirrus, this term is used when the cloud fibers extend outward from an elongated central core and are suggestive of vertebrae, ribs, or a fish skeleton.

Supplementary Features

Clouds may also be identified by the presence of *supplementary cloud features.* Supplementary cloud features are specific portions of a larger cloud. Most supplementary features are associated with cumulonimbus clouds. Virga, tuba (funnel clouds, tornadoes, waterspouts), incus (anvil tops), arcus (roll clouds), wall clouds, mamma (formerly called mammatus), pileus, velum, and pannus are all supplementary features of cumulonimbus clouds. Virga may also be associated with many cumuliform clouds, and pannus with nimbostratus clouds. *Cloud*

Types For Observers has excellent photographs and descriptions of these supplementary features.

CLOUD IDENTIFICATION

Since the only method at present to identify cloud type is by visual identification, you must be familiar with the characteristics of the various clouds. Although NAVMETOCCOMINST 3141.2 and NAVMETOC-COMINST 3144.1 present a good description of the clouds present in the 27 states-of-the-sky, you should be thoroughly familiar with the identification features of each cloud type. Let's take a closer look at some of the important identification features of cloud genera.

Cumulus (CU)

Cumulus, translated from Latin, means "heap." Heap aptly describes a cumulus cloud in most of its stages. Since cumulus clouds form by convective action, the height of their base above the surface is directly related to the amount of moisture near the surface. The higher the moisture content, the lower the cloud base. Although the water droplets in cumulus are very numerous, they are very small in the cloud's early stages. As a cumulus cloud continues to grow, the number of large drops within the cloud increases. These large drops may be precipitated from the cloud or may continue to be suspended by the vertical air currents within the cloud. Precipitation in the form of showers occurs with cumulus clouds of moderate development. Although this precipitation may be of moderate intensity, its duration is usually short lived. These clouds do not produce the heavy rain and high winds that are associated with their bigger brothers, the cumulonimbus.

Occasionally, the showers from cumulus clouds evaporate before they reach the ground. This situation is known as *virga* and is characterized by a dark "fuzzy" area immediately below the nearly uniform base of the cumulus cloud. This darker fuzzy area, caused by the precipitation, decreases in intensity beneath the cloud until it disappears (complete evaporation). When virga consists of snow or ice crystals, the virga is not dark and appears more "wispy." This is due to the greater influence of the wind on the snow and ice crystals; the precipitation trails appear to be bent by the wind.

Cumulus clouds produced by convective heating develop in a distinct sequence. This is the primary means by which convective clouds form within an air mass. The cumulus clouds first appear as cumulus humilis, and then develop into cumulus mediocris and cumulus congestus. Although cumulus congestus may continue to develop into cumulonimbus, the cumulonimbus clouds are identified as a separate cloud genus.

When cumulus clouds are formed by mechanical lift, the sequence is the same. However, early stages of development may not be apparent, especially if stratiform clouds are already present.

CUMULUS HUMILIS.—In the earliest stage of development, cumulus usually forms in, and indicates, good weather. A typical cumulus cloud is shown in figure 1-7 in its formative stage. Point A shows the clearly defined outline, the distinct white color, and the characteristic "bulging" appearance. At point B, notice the characteristic flatter and darker base. In this stage, the cumulus is often called a "fair-weather cumulus" or *cumulus humilis.*

CUMULUS MEDIOCRIS.—When cumulus clouds continue to develop vertically, and reach a moderate vertical extent, they are called *cumulus mediocris* (fig. 1-8). Cumulus mediocris have small cauliflower-like buildups, but rarely produce precipitation other than virga.

CUMULUS CONGESTUS.—Cumulus clouds that continue to develop and to reach moderate vertical extent are called *cumulus congestus. Congestus* generally means the sky is filled with clouds vertically, rather than horizontally. These clouds are identified by several layers of puffy, cauliflower-like buildups

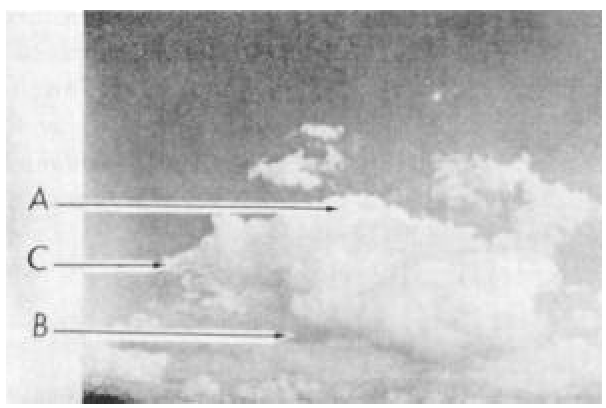

Figure 1-7.—Cumulus humilis cloud.

Figure 1-8.—Cumulus mediocris cloud.

extending upwards from the base (fig. 1-9, view A), and also by their overall size. It is not uncommon to see one or two cumulus congestus cells in the sky surrounded by cumulus mediocris cells.

Rapidly building cumulus congestus cloud cells may produce clouds of great vertical extent with relatively small base areas so that they appear to be in the form of large towers. The cloud is still classified a cumulus congestus cloud, but this appearance is commonly called *towering cumulus* (TCU). Towering cumulus clouds normally do not develop as fast horizontally as they do vertically. A rule of thumb for identifying a cumulus congestus cloud as a towering cumulus is that the height appears to be twice the width of the base (fig. 1-9, view B).

Cumulus congestus cells, and especially towering cumulus (congestus) clouds may produce light to moderate showers. Over warm ocean waters, towering cumulus may produce waterspouts. When a large cumulus congestus cloud begins to produce either a wispy cirrus blow-off or a well-defined anvil-shaped top (the upper portion of the cloud column begins bulging horizontally) or if lightning is seen or thunder is heard, the cloud is automatically classified a different type of cloud: the cumulonimbus.

Cumulonimbus (CB)

Cumulonimbus clouds are generated from large cumulus congestus clouds. These clouds cells are distinguished from cumulus congestus by their massive appearance and extensive vertical development. The presence of thunder, lightning, or an anvil top automatically classifies the cloud a cumulonimbus.

Although cumulonimbus may develop cirrus blow-off in the polar regions or during the winter in the mid-latitudes at 20,000 feet, most commonly the cirrus blow-off or top of the anvil will be somewhere between 25,000 to 45,000 feet in the mid latitudes. Tops of the larger cumulonimbus cells have been measured in the tropics in excess of 60,000 feet.

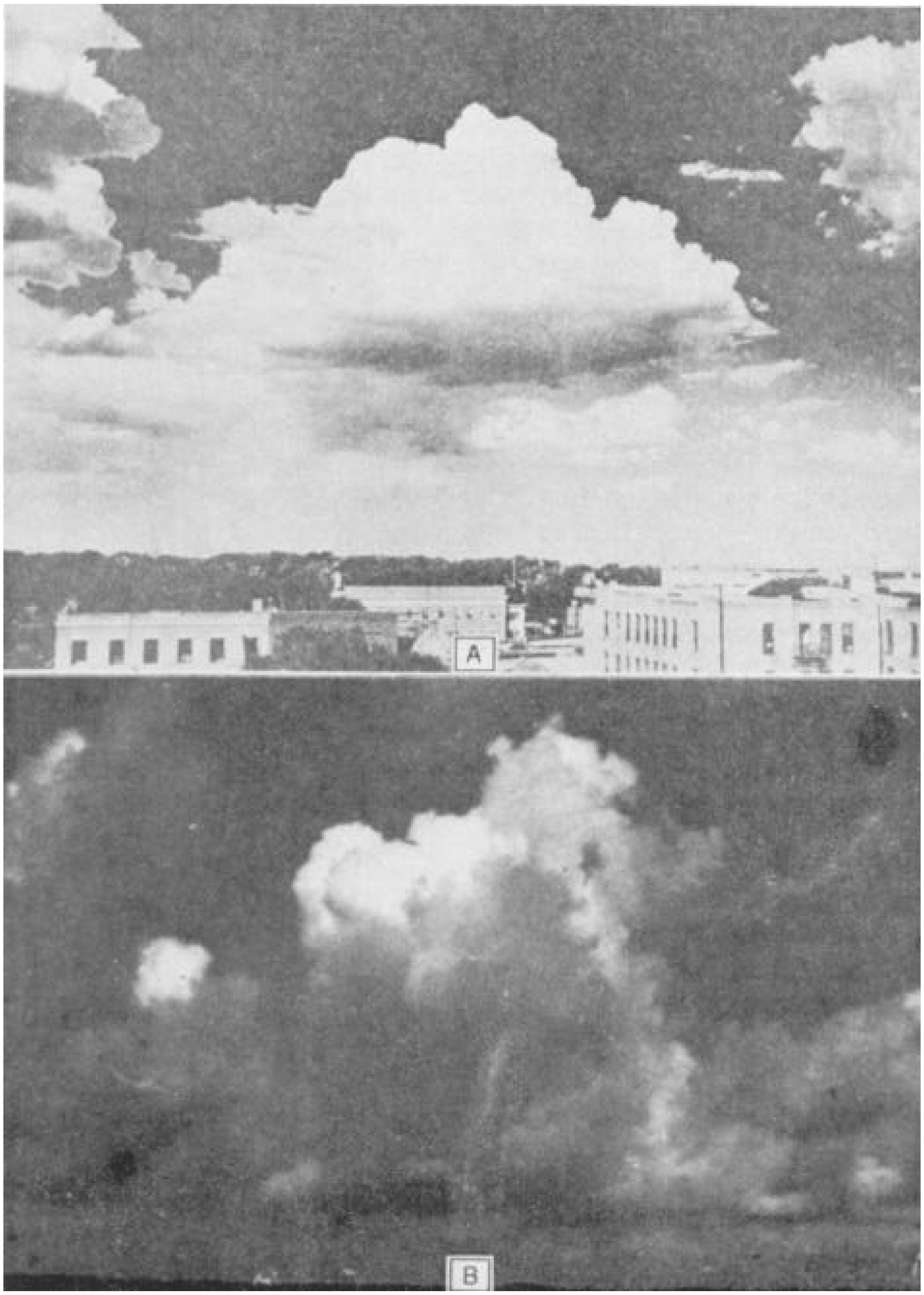

Figure 1-9.—Cumulus congestus. (A) Typical, (B) towering cumulus appearance.

CUMULONIMBUS CAPILLATUS.—The presence of the anvil top (incus) with or without cirrus blow-off identifies a *cumulonimbus capillatus* (fig. 1-10), which is the most recognizable form of cumulonimbus. These clouds, sometimes called "anvil" clouds or "thunderheads," frequently produce thunder, lightning, surface hail, strong and gusty surface winds, and heavy rain.

CUMULONIMBUS CALVUS.—A second species of cumulonimbus, the *cumulonimbus calvus,* lacks the familiar anvil top. Typically, it looks like an extremely large cumulus congestus cell, with less developed cumulus clouds surrounding it and appearing to form a horizontal extension from the base of the larger buildup (fig. 1-11). Although an anvil top, thunder, or lightning need not be observed, the cloud is classified by its size, development, and ominous appearance. Typically, cumulonimbus calvus cells have very dark gray bases. These clouds may later develop an anvil top to become cumulonimbus capillatus. If conditions are not favorable for continued vertical development, cumulonimbus calvus clouds may produce moderate to heavy shower activity as the upward air currents in the cloud loose intensity.

REVIEW QUESTIONS

Q6. How many states-of-the-sky are internationally recognized?

Q7. List the three general cloud forms.

Q8. Stable air is normally associated with what general cloud form?

Q9. Describe the four processes that cool air by lifting.

Q10. Mid-etage clouds in the temperate regions of the earth are found between what levels?

Q11. Define cloud variety.

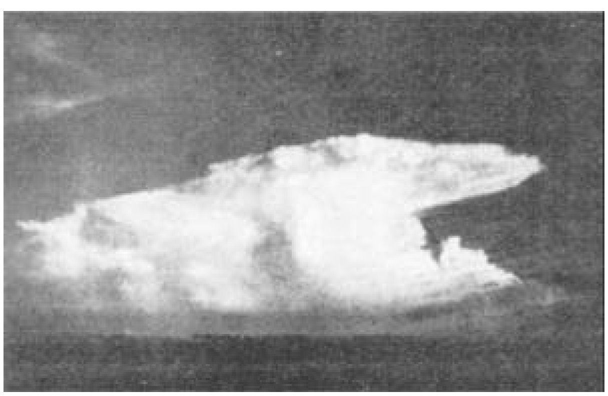

Figure 1-10.—Cumulonimbus capillatus (anvil cloud—note that cirrus blow-off has not occurred.

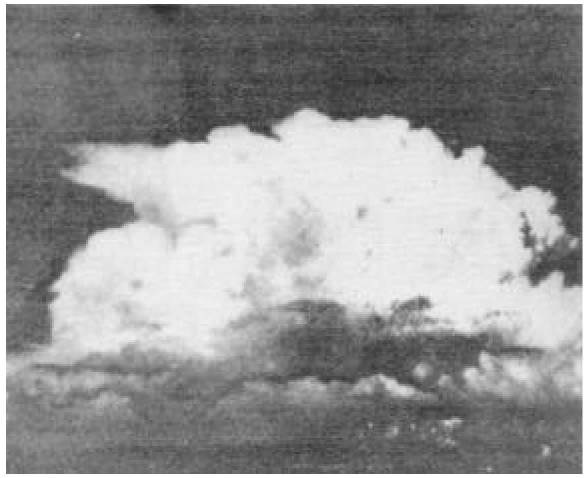

Figure 1-11.—Cumulonimbus calvus cloud.

Q12. Most supplementary cloud features are associated with what type of cloud?

Q13. The height of the base of cumulus clouds is directly related to what factor?

Q14. What is a simple rule of thumb for classifying cumulus congestus clouds as towering cumulus?

Q15. Cumulonimbus capillatus clouds are identified by what distinguishing feature?

SUPPLEMENTAL FEATURES.—Many supplemental cloud features of cumulonimbus clouds indicate the stage of development or the potential severity of the “storm.”

Light precipitation can begin to fall while the cloud is still increasing in size. Heavy precipitation indicates the cell has slowed or stopped increasing in height. With the beginning of heavy precipitation, the cloud base becomes rougher and less clearly defined. Smaller, ragged, or fragmented clouds are frequent under the base of the dissipating CB cell. These ragged cloud elements are the species *cumulus fractus* (fig. 1-12) if they are more or less in individual elements, or *stratus fractus* if they form a mostly continuous layer. Collectively, the layer of fragmented elements is called *pannus*—a supplemental cloud feature. Cumulus fractus or stratus fractus clouds, often called "scud," usually are associated with falling precipitation or found in the vicinity of numerous showers. Pannus may exhibit very rapid movement under the CB cell base, with individual elements moving in a radically different direction than that of the CB cell. For example, it would not be uncommon to see a CB cell moving toward the northeast, with a low layer of pannus moving toward the south.

Figure 1-12.—Cumulus fractus cloud in a pannus layer.

The upper portion of the CB cell becomes broader and the top may become very indistinct as cirrus and dense cirrus clouds develop from the ice crystals blowing downwind from the top portion of the cell. The cirrus blow-off shield may extend well downstream of the CB cell. Then, the shield may thicken downward, becoming dense enough to blot out the shape of the sun (fig. 1-13). Sometimes the dense cirrus blow-off *(cirrus*

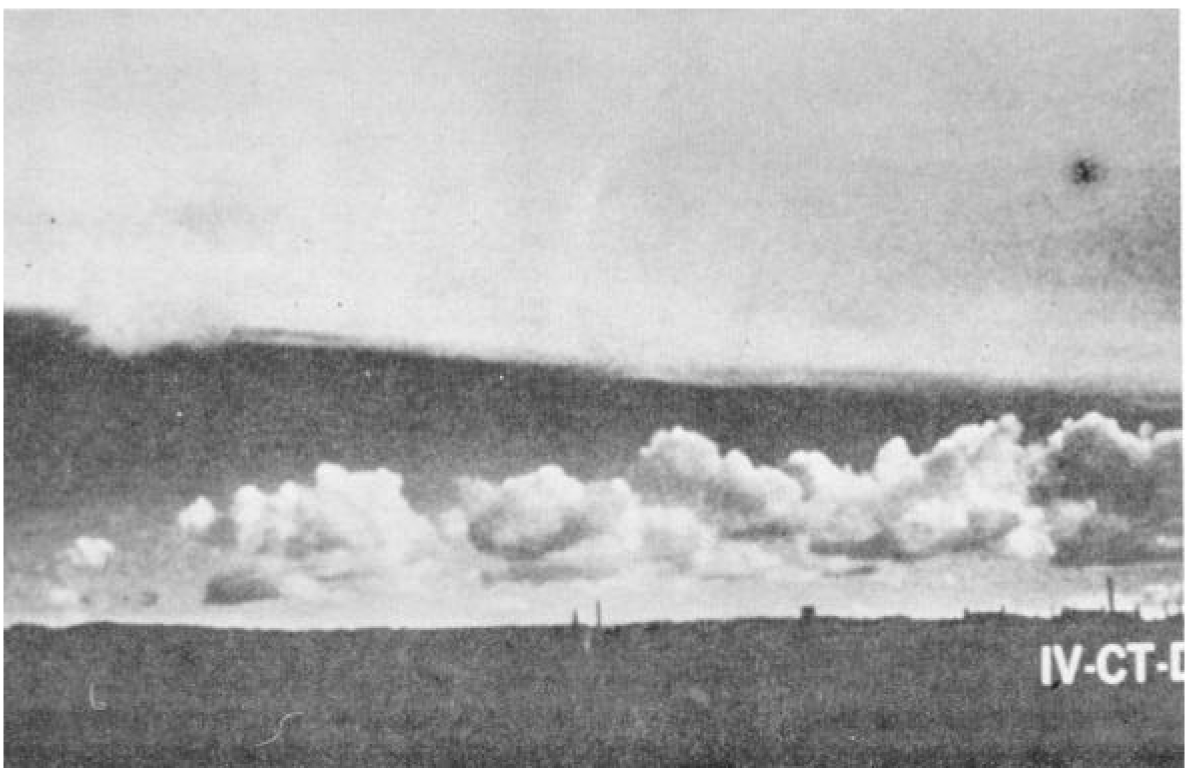

Figure 1-13.—Dense cirrus blow-off (cirrus spissatus) from a thunderstorm.

spissatus) will continue to thicken downward enough to be classified altostratus. Occasionally, rounded bulges may develop, protruding from the base of the dense cirrus blow-off. Although found on the dense cirrus or altostratus blow-off from a cumulonimbus cell, these rounded bulges are called *cumulonimbus mamma,* or simply *mamma* (fig. 1-14). Mamma is a strong indicator that conditions are favorable for severe weather to occur under and near the cumulonimbus base. Mamma should NOT be interpreted as developing funnel clouds.

During the dissipation stage, there are more pronounced downdrafts within the cloud than updrafts. The remaining updrafts may become more concentrated and originate from the rear portion of the cloud cell. Severe weather, such as strong or gusty surface winds, heavy rain, hail, and tornadoes, usually is confined to the dissipating stage.

The beginning of the dissipation stage may be marked by the sudden onset of strong, cold downdrafts, *known* as a *downrush,* exiting the base of the cloud. These winds are deflected by the ground to create very gusty, sometimes dangerously strong winds blowing outward from under the cloud cell. The leading edge and upward boundary of the bubble of gusty winds form a distinct boundary known as the *gust front* or the *outflow boundary. The* outflow boundary—a sharply defined separation between the wind flowing toward the base of the cloud cell and the strong, cold, outward flowing wind-typically is associated with *low-level wind shear* (LLWS), a dangerous phenomenon that has caused many fatal aircraft crashes. A particularly strong, concentrated downrush from the base of the cloud is *known* as a *microburst.* A microburst produces concentrated, extremely strong straight-line winds blowing outward from the base of the CB cell. Typically, these winds produce great damage and are often initially and incorrectly reported by the public as a tornado.

A *roll cloud (arcus)* may form along the leading edge of the cumulonimbus cloud base during a downrush. The ragged bottom edge of the roll cloud is usually much lower than the more uniform base of the

Figure 1-14.—Cumulonimbus mamma on mid-etage altostratus cloud layer.

CB cell (fig. 1-15). It may extend along the entire outer edge of the base of the CB cell, or may angle out slightly ahead of the CB base with the top of the outflow boundary. Although with weaker gust fronts, the roll cloud may appear rough, ragged, or bumpy, under certain conditions the roll cloud may appear very smooth. Roll clouds indicate that thunderstorm downrush has occurred and that LLWS may be present.

The turbulent action along the cold air outflow boundary may produce small-scale vortices on the ragged base of the roll cloud. These vortices sometimes take on the appearance of small, ragged funnel clouds. The public commonly mistakes these vortices for funnel clouds and occasionally reports them as funnel clouds. These vortices are known as *cold-air funnels.* Rarely, a cold-air funnel will develop sufficiently to reach the surface. It does not have the strength of a true funnel cloud or tornado, and is about as powerful as a strong dust devil. By itself, it may be able to pick up objects, such as trash cans or to shake a small camp trailer. Usually, the damage associated with sightings of cold-air funnels is caused by the much more powerful straight-line winds in and behind the outflow boundary (gust front) that produced the cold-air funnel.

Another phenomenon associated with the outflow boundary is a *dust cloud* on or near the earth's surface. This phenomenon is frequent in desert areas and is fairly common in other areas after a dry spell. The dust often appears to be rolling outward and upward from the ground as it moves over an observer. It is associated with the first gust of a thunderstorm's gust front.

A *wall cloud,* a sometimes hollow, generally circular patch of cloud with a ragged bottom edge, may lower from the base of a CB cell. A wall cloud is usually much smaller than the base of the CB cell, and will usually form in the right rear quadrant of the CB cell with respect to the CB's movement. When viewed from the side of the CB, the wall cloud usually is under the rear portion of the cell, where the billowy cloud tops appear to be tapering from the anvil top downward toward the rear portion of the cell. A slowly rotating or spinning wall cloud is an indication of a very strong thunderstorm and impending funnel-cloud development.

Funnel clouds (tuba) usually form on the edge of the wall cloud or near the wall cloud at the rear of the storm. In the early stages of development, the funnel cloud may be only a rotating rounded bulge extending

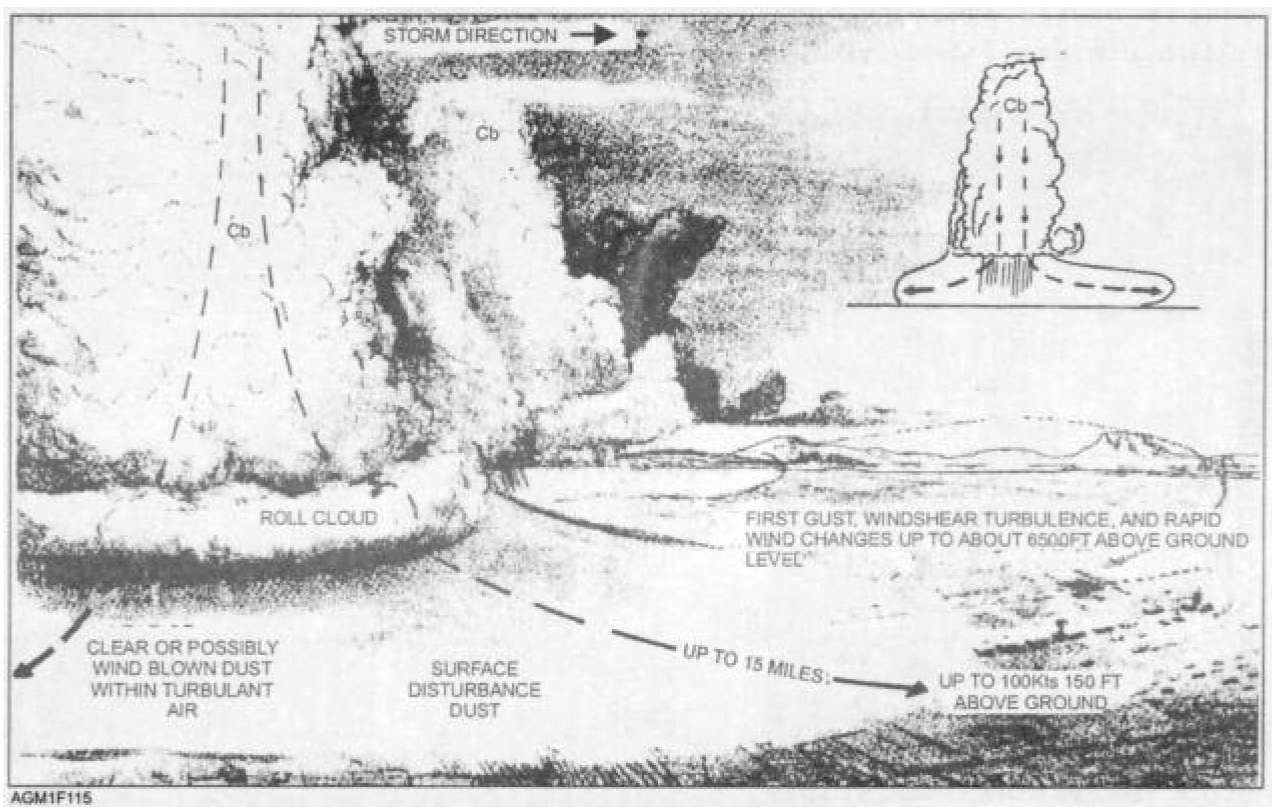

Figure 1-15.—Roll cloud formation on cumulonimbus.

from the base of the CB cell. As the funnel develops, it will gradually assume the more common cone-shaped appearance. When the funnel cloud (fig. 1-16) extends downward from the CB base to a point where its circular rotation reaches the ground, it is then called a *tornado* (fig. 1-17). Funnel clouds and tornados contain destructive, concentrated, cyclonic winds in excess of 150 knots. The force of the wind is amplified by the rapid change in the direction of the winds as the tornado passes over an area. Estimates based on damage equate the force of tornados to straight-line winds of near 500 miles per hour. Funnel clouds can be seen due to the visible moisture from the parent cloud. Under a funnel cloud, the rapidly circulating winds may be invisible until the circulation picks up dust and debris from earth's surface.

Figure 1-17.—Tornado.

Waterspouts (fig. 1-18) develop over warm ocean or bay waters more frequently than overland. They have been observed from the bases of rapidly building towering cumulus cells, often without any precipitation occurring. They are generally weaker than tornadoes, but still contain dangerous, destructive winds.

When conditions are favorable for tornado development, waterspouts may be assumed to be as strong as a tornado. But when conditions are NOT favorable for tornadic development, then any waterspouts that form are usually less powerful. A Great Lakes freighter, S.S. *Edmond Fitzgerald,* was lost

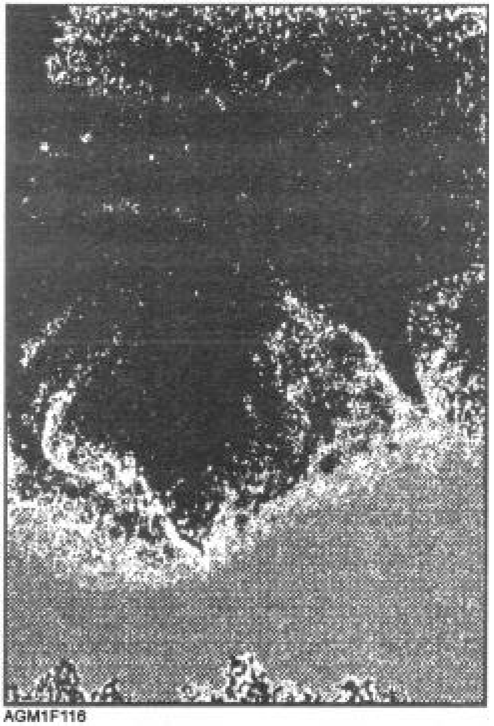

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Figure 1-16.—Funnel clouds.

Figure 1-18.—Waterspout.

with all hands after being struck by a waterspout. This strong waterspout was associated with a tornado outbreak over the Great Lakes region. Off the west coast of Mexico in late 1989, a cruise liner was hit by a weaker waterspout that broke many windows and caused some minor structural damage. This weaker waterspout formed in conditions that were NOT favorable for tornado development. Nontomadic waterspouts are thought to be well-developed, cold-air funnels.

Hail may begin forming in the building stage as water drops are carried above the freezing level. It may fall from the cloud base as the updrafts weaken, or become more concentrated during the dissipating stage. Hail frequently is thrown out the top and sides of building and mature CB cells, and may travel up to 25 miles from the cell. This hail rarely reaches the surface before melting. During the dissipation stage, however, the stronger, colder downdrafts tend to bring the hail to the surface UNDER the cloud base before it has a chance to melt. Most frequently, hail reaches the ground in the general vicinity of the wall cloud. The size of the hail is dependent on many factors within the cloud, which you will study later in preparation for AG2.

Another accessory cloud associated with large cumulonimbus buildups are the layers of altocumulus or altostratus clouds, often seen developing from the mid-portion of the cumulonimbus column. These clouds are formed by the spreading out of moisture into a thin, somewhat more stable layer of atmosphere as the unstable column of air in the building cumulus punches through the layer. These cloud layers are considered part of the cumulonimbus cell and are called *velum.*

Occasionally, a rapidly building cumulus will approach a layer of mid-level or upper-level stratiform clouds and appear to push the cloud layer upwards, forming a cap-shaped feature above the cauliflower top of the cumulus or cumulonimbus cell. Until the cumulus cell makes contact with the bulging cloud layer, the cap-shaped feature is called *pileus.*

Stratocumulus (SC)

Clouds in the genus stratocumulus appear to be a combination of the smooth, even, stratiform cloud and the puffy cells of the cumuliform clouds. Stratocumulus clouds are distinguished from cumulus clouds by their flatter appearance. Stratocumulus typically appear to be tightly-packed, flattened cumulus cells but with less distinct edges (fig. 1-19). As stratocumulus cloud elements merge into a continuous layer, they appear gray with dark areas. These dark areas are the thicker portions of the SC clouds.

Stratocumulus is sometimes mistaken for altocumulus, which is the same type of cloud form in the

Figure 1-19.—Stratocumulus cloud.

mid-etage (fig. 1-20). Because of their greater height, the elements of altocumulus clouds appear smaller than stratocumulus cloud elements. The best way to judge whether a cloud is altocumulus or stratocumulus is by obtaining the height from the ceilometer or other cloud-height sensors. Alternatively, an estimate of the size of the individual elements is a reliable indicator. Individual elements of stratocumulus clouds are wider than 5°, while the individual elements of altocumulus are narrower than 5°. The width of your three middle fingers held at arm's length is about 5°.

Precipitation rarely occurs with stratocumulus clouds. When it does occur, it tends to be very light and intermittent. Light snow showers (snow flurries) are the most common form ofprecipitation from stratocumulus clouds. Due to the light intensity of stratocumulus-produced precipitation, more often than not any precipitation will be in the form of virga.

The major species of stratocumulus clouds are stratocumulus floccus, stratocumulus castellanus, and stratocumulus stratiformis.

STRATOCUMULUS FLOCCUS.— *Sirato-cumulus floccus* clouds appear as tightly-packed, flattened cloud cells in a layer, with higher clouds or blue sky visible in the area between the cells. Individual cells have very indistinct, feathery edges.

STRATOCUMULUS CASTELLANUS.—In the species *stratocumulus castellanus,* the individual cloud cells develop in a stratiform layer. These cells usually have rather indistinct edges and scattered cumuliform buildups protruding upward from the generally flatter tops of the stratiform cloud layer. These buildups are commonly in the form of small towers or tufts.

STRATOCUMULUS STRATIFORMIS.— When a layer of cumulus humilis or cumulus mediocris cloud cells begins to lose the clear definition on the edges, such as is seen beginning at point C in figure 1-7, the layer is classified *stratocumulus stratiformis.* As development continues, these cells may merge, completely tilling in the clear gaps between the cloud cells.

Stratus (ST)

Occasionally, a layer of stratocumulus is mistaken for a stratus cloud. The base of a stratus cloud has a very smooth and uniform appearance, often appearing fuzzy or indistinct. A stratus cloud base may have slightly darker areas, but the darker patches are not arranged in any regular pattern.

Stratus usually forms very close to earth's surface, and is called fog when it is in contact with or within 50 feet of the surface. Stratus clouds may form in conjunction with other higher clouds.

Figure 1-20.—Lower mid-etage altocumulus cloud.

Stratus is capable of producing only very light precipitation, such as drizzle or snow grains; or during extremely cold temperatures, ice crystals. Heavier precipitation, such as showers, accompanied by a very dark portion of the stratus layer, indicates the presence of embedded or higher level cumuliform clouds. Rain or snow would be a strong indication that the cloud layer is NOT stratus, but actually the mid-level cloud, nimbostratus. Another factor that indicates that the cloud layer is nimbostratus rather than stratus is the presence of stratus fractus clouds.

The appearance of the sun through the cloud layer is another indication of the cloud type. If a sharp, well-defined outline of the sun can be seen through a cloud layer, the cloud layer may be stratus. If, however, the outline of the sun is blurred, fuzzy, or appears to be viewed through ground glass, the cloud layer may be altostratus.

One of the key indicators of stratus clouds lies in the previous observation record. Stratiform cloud layers normally do not suddenly develop or move over an area. They are associated with stable layers in the atmosphere and evolve slowly. A hazy layer aloft or at the surface will gradually thicken with time to form stratus or fog. When moving over an area, a very thin or hazy layer will gradually become denser as the stratiform layer movement progresses. The exception to this is the fog banks found over large bays and coastal waters. These fog banks may have very distinct boundaries. As they move overland, they may stay on the ground as fog or may lift slightly, forming a low stratus layer. The transition from clear skies and unrestricted visibility to low overcast stratus and poor visibility in fog may be very sudden. The observation record, however, would note the presence of the moving fog bank.

STRATUS NEBULOSUS.—When stratus forms in a layer with no distinct features or denser portions, it is termed *stratus nebulosus.* Stratus nebulosus is the most common form of stratus (fig 1-21).

STRATUS FRACTUS.— *Strutus fractus* clouds form in more or less continuous layers. They present a ragged appearance, as if shredded by the wind. Stratus fractus clouds are generally indicators of bad weather and are usually found below layers of nimbostratus clouds. As with cumulus fractus clouds, a layer of clouds of the species stratus fractus is called "pannus."

Altostratus (AS)

This mid-etage cloud has features similar to stratus, as we have previously discussed. Although the height of the cloud base is the primary difference between stratus and altostratus, the cloud composition is another important clue. Altostratus clouds frequently form above the freezing level. In North America, the freezing level during the winter may be at the surface; but during summer the freezing level may range from 4,000 feet to 16,000 feet, depending on location and weather patterns. The range between 8,000 to 10,000 feet is a fair mean freezing level for the continental United States. When altostratus clouds form above the freezing level, they consist of ice crystals and super-cooled water droplets (water at or below freezing that has not crystallized). Ice crystals give the altostratus clouds their grayish or bluish color and the customary fibrous appearance. The ice crystals also diffuse light more, such that the sun will appear as though viewed through ground glass.

Figure 1-21.—Stratus cloud.

Another indicator used to differentiate between altostratus, stratus, and the higher cirrostratus clouds is the presence and type of optical phenomena. We must consider two types of optical phenomena at this point: the corona and the halo.

A *corona* is a reddish or brownish ring of small diameter seen around the sun or the moon when viewed through clouds. It is often easier to see in a reflection off calm water than by direct observation. A corona may occasionally display very pale rainbow colors, but red will normally predominate and show in the outermost ring. The corona is produced by refraction of light in liquid water droplets, such as the super-cooled droplets found in altocumulus clouds. It is rare for even super-cooled water droplets to exist at too high an altitude, so a corona usually indicates a low or mid-etage cloud form. Large droplets produce a small corona, while smaller droplets produce a larger corona.

A *halo* is a 22° diameter ring seen encircling the sun or moon when viewed through clouds. The ring may show pale colors of the spectrum. Occasionally a secondary ring of 46° diameter may be visible encircling the 22° ring. Bright spots, which are called *mock suns,* may appear on the halo in a horizontal plane with the sun. A bright horizontal line may appear to connect the mock suns and the actual sun, which is called the *parhelic circle.* Occasionally, vertical columns of light, or *pillars,* may appear above and below the sun or moon at low elevation angles, which intersect and form bright spots on the 22° halo.

In the mid latitudes, the corona usually indicates that the cloud is a mid-etage cloud. It is only rarely observed in higher low-etage stratus clouds and the lowest high-etage stratiform clouds. The presence of a halo, on the other hand, will indicate that the cloud is a high-etage cloud form, most often cirrostratus, and it may occasionally occur with cirrus. It does not occur with altostratus clouds.

During the day, an indicator of altostratus is the absence of shadows on the ground. If the sun is seen through a stratiform cloud and shadows are present on the ground, the cloud could be either altostratus or cirrostratus. However, if the cloud is dense enough to prevent shadows from forming, it should be classified as altostratus. Cirrostratus is never dense enough to prevent shadows during the daylight hours.

The height of the base of the altostratus clouds may range from 6,500 feet to 23,000 feet. The density of the stratiform cloud is the primary determining factor of stratiform cloud typing in the 18,500 to 23,000 foot range, while the presence of the corona and halo may be used as reliable secondary indicators.

There are no species associated with altostratus clouds, although there are several different varieties.

Nimbostratus (NS)

Usually formed from altostratus clouds thickening downward, nimbostratus, commonly called "the rain cloud," ranges in color from medium to very dark gray, with a diffuse, indefinite base. It is always thick enough to obscure the sun and is almost exclusively found near frontal zones. Stratus fractus clouds are commonly found under nimbostratus cloud layers, especially just prior to the start of precipitation and during light precipitation. The stratus fractus tend to dissipate during heavier precipitation. Nimbostratus clouds may also form from dissipating cumulonimbus clouds.

Although nimbostratus is classified as a mid-etage cloud, its base often lowers well into the low-etage. With approaching occluded and warm frontal systems, nimbostratus may lower to within several hundred feet of the ground. Nimbostratus bases with stationary fronts tend to be slightly higher.

Normally, altostratus is reclassified as nimbostratus when the cloud base becomes very dark or stratus fractus clouds are observed under the base of the layer. Altostratus clouds must be reclassified as nimbostratus when precipitation begins or when bases drop to less than 6,500 feet. Nimbostratus clouds are usually distinguished from opaque altostratus clouds by the more diffuse, but denser and darker appearance of the base, which is often described as appearing "wetter" than altostratus.

The genus nimbostratus has no distinct species or varieties.

Altocumulus (AC)

Altocumulus clouds are composed of super-cooled water droplets and ice crystals when located above the freezing level. Altocumulus clouds look very similar to stratocumulus clouds; the primary difference in their classification is by height, which may be inferred by the size of the elements in the cloud. We have already discussed how to differentiate between stratocumulus and altocumulus clouds based on the size of the elements. Unfortunately, the altocumulus clouds in the middle to upper portion of the mid-etage (fig. 1-22) and the still higher cirrocumulus clouds of the high etage (fig. 1-23) also look very similar. If the cloud elements are larger than the width of one finger held at arm’s length, the cloud should be classified as altocumulus. If the individual cloud elements are smaller than the width of a finger held at arm’s length, the cloud should be classified as cirrocumulus. Do not use this method unless the cloud in question is more than 30° above the horizon.

Altocumulus clouds appear white to light gray, or mottled with shadings between white and light gray. When altocumulus clouds do not present a uniform appearance, you should consider other identifying features. Virga may occur from altocumulus clouds, but the trails appear shorter than those associated with stratocumulus. Based on the known height of the freezing level, the bent virga trails associated with frozen precipitation may indicate whether the cloud is high enough to be altocumulus.

The presence of a corona is most frequently associated with altocumulus clouds, even more so than

Figure 1-22.—Typical altocumulus cloud.

with altostratus clouds. Mock suns or pillars, without the surrounding halo, indicate high level altocumulus clouds composed mainly of ice crystals. *Irisation, the* pastel shading of cloud element edges with colors of the spectrum, occurs in ice crystal clouds, which, based on the known freezing level, may help rule out stratocumulus clouds. Irisation may occur with cirrocumulus clouds.

Altocumulus clouds are classified in four species, and have more varieties than any other cloud form. The four species of altocumulus clouds are altocumulus castellanus, altocumulus floccus, altocumulus stratiformis, and altocumulus lenticularis. The

Figure 1-23.—Typical cirrocumulus cloud.

lenticularis species is discussed in a following section on "Orographic Clouds."

ALTOCUMULUS CASTELLANUS.— *Altocumulus castellanus* cloud elements build upward from the base to form towers, tufts, or "turrets." The tops and edges of the buildup may appear ragged, and not have the smoother rounded appearance or cauliflower-like tops. The ragged tops are sometimes described as looking similar to the turrets on a medieval castle, which gives some reference for the name "castellanus." Usually originating in the lower portion of the mid-etage, these clouds may build upwards to moderate or great extent, and are similar to towering cumulus, except with high bases and smaller appearing elements. Continued development may, in rare situations, produce cumulonimbus clouds. Virga is common, and even light precipitation reaching the ground is not uncommon with altocumulus castellanus.

ALTOCUMULUS FLOCCUS.—Related to the altocumulus castellanus is the less developed altocumulus floccus cloud form. *Altocumulus floccus* resemble small, ragged cumulus humilis and typically appear as small tufts of white cloud with rounded or bulging tops. They often have small fibrous trails of virga extending from ragged bases. Both altocumulus castellanus and altocumulus floccus indicate approaching frontal systems with conditions favorable for thunderstorm activity.

ALTOCUMULUS STRATIFORMIS.— *Altocumulus stratiformis* is by far the most common form of altocumulus. In this form we typically see an extensive layer of cloud with smooth, evenly spaced rounded cells or just a cell-like pattern in a generally stratiform layer. Figure 1-22, a typical altocumulus cloud, is a good example of the species altocumulus stratiformis.

Cirrus (CI)

Cirrus clouds, a high-etage cloud type, form generally between 16,500 feet and 45,000 feet in the mid-latitudes. Cirrus clouds are composed of ice crystals.

CIRRUS UNCINUS.—The most common form of cirrus is the thin strand-like wisps of cloud filaments, often curved at on end and described as hook-shaped and called *cirrus uncinus* (fig. 1-24). These cirrus clouds are popularly called "mare's tails" because of their resemblance to the tail of a galloping horse.

CIRRUS SPISSATUS.—The dense blow-off from the top of a cumulonimbus, which looks similar to stratus or altostratus clouds, is called *cirrus spissatus*, but is often referred to as dense cirrus (refer to figure 1-13). Although this cloud typically presents a stratiform appearance, it is not called cirrostratus, because, by definition, cirrostratus is <u>never</u> dense enough to hide the sun. Cirrus spissatus usually forms in a single large patch with a distinct edge. This cloud is reclassified as altostratus when the base lowers to less than 23,000 feet.

A different variety of cirrus spissatus also forms from phenomena that have nothing to do with cumulonimbus blow-off or dissipating cumulonimbus cells. When dense cirrus is formed by other means than by cumulonimbus blow-off or dissipating cumulonimbus clouds, it will frequently be seen as many dense patches at different levels (cirrus spissatus duplicatus), often mixed with thin cirrus filaments. Another variety, cirrus spissatus intortus, is sometimes described as looking like "entangled sheaves" of cirrus clouds. When viewed toward the sun, the denser patches often have gray bases.

CIRRUS FLOCCUS AND CIRRUS CASTELLANUS.—Patches of dense cirrus may take on the form of *cirrus floccus,* with the upper portion of the patch forming rounded tufts, and the base portion becoming ragged. Dense cirrus patches may also grow turrets or battlements and become *cirrus castellanus.* Both cirrus floccus and cirrus castellanus may have ice crystal virga trails showing from the base of the cloud patch, and may be slightly larger than the standard 1°. (Also see cirrocumulus floccus and cirrocumulus castellanus.)

Cirrostratus (CS)

Cirrostratus clouds usually appear as a thin white veil over the sky. If the cirrostratus clouds are very thin and of uniform thickness, the only indication of their presence may be a faint halo, or a whitish tint to the sky. As long as the sun is higher than 30° above the horizon, cirrostratus clouds should not be able to block the sun; shadows should be apparent from sunlight shining through this cloud. When cirrostratus is low on the horizon, it tends to block the blue color of the sky more thoroughly because it is viewed on an angle, and it is commonly mistaken for denser altostratus. This also happens near sunrise and sunset with low sun angles. Cirrostratus cloud layers appear to move very slowly, and change shape very slowly. Typically, the edge of a cirrostratus layer is so indistinct that it is difficult to detect where the blue sky ends and the cloud begins. If movement or changes in shape are detectable during the observation period, the cloud near the horizon may well be altostratus.

Figure 1-24.—Cirrus uncinus (mare's tails).

CIRROSTRATUS NEBULOSUS.—*Cirrostratus nebulosus* often appears as a thin veil over the sky, without any distinguishable features. This cloud is sometimes mistaken for haze. Haze, however, will have a yellowish or brownish color as opposed to the milky appearance of cirrostratus. A halo in an otherwise clear sky indicates cirrostratus nebulosus.

CIRROSTRATUS FIBRATUS.—Occasionally a cirrostratus layer contains fibrous filaments. When this occurs, the entire cloud layer is classified *cirrostratus fibratus.*

Cirrocumulus (CC)

Cirrocumulus clouds are very similar in appearance to the high altocumulus clouds. The small white cells of cirrocumulus clouds, however, cover less than 1° of the sky, which means that they may be hidden by one finger held at arm's length. The small cloud elements are usually arranged in tightly packed rows. An area of cirrocumulus clouds (refer to figure 1-23) is frequently described as looking like a honeycomb, a fish net, or like the scales of a fish. The last description gave rise to the popular name for these clouds, the mackerel sky.

CIRROCUMULUS STRATIFORMIS.—Cixrocumulus clouds in an extensive sheet or layer are identified by the species *cirrocumulus stratiformis.* Typically, however, the area covered by cirrocumulus does not cover the entire sky, but only small patches of the sky.

CIRROCUMULUS FLOCCUS.—When the cirrocumulus elements show rounded tops and ragged bases, often with short virga trails, the *cirrocumulus* *floccus* species name is used. When the virga trails make the entire element larger than 1°, the cloud must be classified cirrus floccus.

CIRROCUMULUS CASTELLANUS.—*Cirrocumulus castellanus* identifies the cirrocumulus cloud layers where each element shows a cumuliform buildup such that the height of the element is greater than the width of its base, and each element is smaller than 1°. If the vertical development of the cloud elements progresses such that the element becomes larger than 1°, the cloud is reclassified *cirrus castellanus.* Now let's consider some cloud types we haven't covered in table 1-1.

Orographic Clouds

Several species of low-, mid-, and high-etage clouds are associated only with moist airflow over mountainous areas.

These clouds usually form during Mountain Wave conditions, when strong winds blow across mountain ranges. The presence of these clouds is significant in that they may be associated with dangerous turbulence. All of the orographic cloud forms are unique in that they are stationary over a particular area and do not move with the wind flow. Slow changes in the arrangement of elements or the cloud pattern may be noted as the upper wind direction or intensity changes. The significant orographic cloud forms are the rotor cloud, the cap cloud, and the lenticular clouds.

The *rotor cloud* (fig. 1-25) is formed downwind from the mountain range. The rotor cloud is formed as the strong winds moving across the mountains set up a wavelike action in the winds downstream from the mountain. The waves or eddies in the air may extend in a series downstream from the mountain for hundreds of miles. The upward moving air in the waves or eddies, if moist enough, is brought to saturation as it rises, forming the rotor clouds.

Rotor clouds are cap-shaped, with smooth rounded tops, flattened or concave bases, ragged up-wind edges, and very ragged downstream edges. The up-wind edge continuously forms, while the downstream edge continuously dissipates. Rotor clouds may form as a few isolated elongated elements, or in succeeding bands elongated parallel to the mountain range. When you are observing the sky condition, rotor clouds are usually classified as cumulus clouds, and a note about the presence of rotor clouds may be added in the remarks section.

A special type of stratocumulus cloud, called the *Foehnwall* or *cap cloud,* may form on the top of mountain ranges, resembling a "cap" on the mountain. It is formed as moist air is forced upward by the mountain top, and dissipates on the leeward side of the mountain as the moving air descends. Cloud particles and denser patches of cloud may be seen moving over the mountain and occasionally may be seen flowing down the leeward side of the mountain, giving the appearance of a waterfall. The cloud itself is stationary on the mountain top.

Altocumulus lenticularis (abbreviated ACSL) clouds are typically described as lens-shaped, almond-shaped, or cat-eye shaped, and usually have a windswept appearance (fig. 1-26). Although the cloud elements may grow or shrink in size, they are usually stationary. The size of the individual cloud elements is usually quite large. The leading or windward edge

AGM1F125

Figure 1-25.—Rotor cloud-an orographic form of cumulus cloud.

AGM1F126

Figure 1-26.—Standing lenticular cloud.

continuously forms, while the trailing or leeward edge continuously dissipates.

These clouds usually form downwind from a mountain range or over a mountain in a small portion of the sky at one level, but may form in different levels and appear stacked on top of the lower level cloud elements. They may also form in a layer downwind from a mountain range with individual cloud elements well separated from each other. Lenticularis clouds need not form in conjunction with other orographic clouds, the rotor clouds, and cap clouds.

The process that forms altocumulus lenticularis clouds also on occasion forms the same clouds closer to the ground in the low-etage, and frequently forms similar clouds in the high-etage. The difference in the classification of stratocumulus lenticularis, altocumulus lenticularis, and cirrocumulus lenticularis stems solely from the height at which they form, and should not be based on the apparent size of the cloud, which, in this case, may be very misleading. Studies have shown that although lenticularis clouds usually form with bases in the mid-etage range, they can form downstream of larger mountain ranges, with the base of the lowest lenticularis in the 20,000- to 30,000-foot range. Bases of the higher elements of stacked lenticularis may be as high as 35,000 feet, with cloud tops near 40,000 feet.

REVIEW QUESTIONS

Q16. Describe two potentially dangerous wind phenomena associated with an outflow boundary.

Q17. A wall cloud will usually form in what location of a CB cell?

Ql8. Stratus fractus clouds generally form in conjunction with what other type of cloud?

Q19. When must altostratus clouds be reclassified as nimbostratus?

Q20. What might the formation of altocumulus castellanus or altocumulus floccus indicate?

Q21. What are cirrus clouds composed of?

Q22. Explain the formation of a rotor cloud.

Q23. Explain the formation of a cap cloud.

CLOUD AMOUNTS

The amount of cloud cover is the second determination you must make in observing the overall condition of the sky. Clouds of the types we have just discussed may form at various levels in the atmosphere. It is not uncommon to have different layers of low-etage clouds, along with several layers of mid- and high-etage clouds.

Estimation by the observer is the primary method used to determine cloud amounts. However, automatic weather systems can measure the amount of clouds at each level, and these inputs may be used as a supplemental tool by observers for cloud layer coverage and total sky cover.

Generally, there are two different types of cloud amount measurements necessary for an observation. The more difficult measurement is *cloud layer coverage.* The easier measurement is *the total sky* cover. In cloud layer coverage, the amount of cloud in each layer must be estimated. Both are estimated in eighths *(oktas)* of *the celestial dome* (the total area of sky or the dome of the sky). Layer coverage is used to determine the *cloud ceiling,* which is the lowest layer or layers that block 5/8 or more of the celestial dome from being seen.

Layer Coverage

A cloud *layer* is defined as "clouds and/or obscuring phenomena aloft, either continuous or composed of detached elements, that have bases at approximately the same level." Both continuous and detached elements may combine to form a layer, and all layers and obscuring phenomena are to be considered opaque. The essential requirement is that bases be at approximately the same level. The upper portions of cumulonimbus clouds are often spread horizontally by the wind, and form a layer of cirrus spissatus, dense altostratus, or dense altocumulus clouds, Velum may also be present. These horizontal extensions are regarded as separate layers if their bases appear horizontal, and they cover 1/8 of the sky or more. A layer may be a combination of cloud types or a combination of obscuring phenomena as long as the bases are all at approximately the same level. For example, cumulus mediocris and cumulus congestus may be considered as the same layer if their bases are the same height.

When observing layer coverage, you must not only estimate the amount of clouds in each layer, but also consider phenomena that hide 1/8 or more of the sky as a layer. (A partial obscuration hiding less than 1/8 of the sky is ignored.) Obscurations may be surface-based or aloft and include phenomena such as rain, snow, fog, smoke, or haze. However, liquid or frozen water particles falling through the atmosphere are never classified as obscurations aloft. In the past, you may have looked at the sky and seen thin fog or haze on the horizon that blocked your view of the clouds. Sometimes the portion of the sky that is hidden from view extends only a few degrees above the horizon, while at other times, the phenomenon may extend well above the horizon. When the phenomenon is thin enough to allow the sun, clouds, the moon, or stars to be seen overhead but not seen near the horizon, the phenomenon is termed a *partial obscuration* (fig. 1-27). If the phenomenon is dense enough to hide even the portion of the sky directly overhead, it is called a *total obscuration.* An obscuring phenomenon frequently extends around the entire horizon circle, 360° of azimuth, to completely surround the observation site.

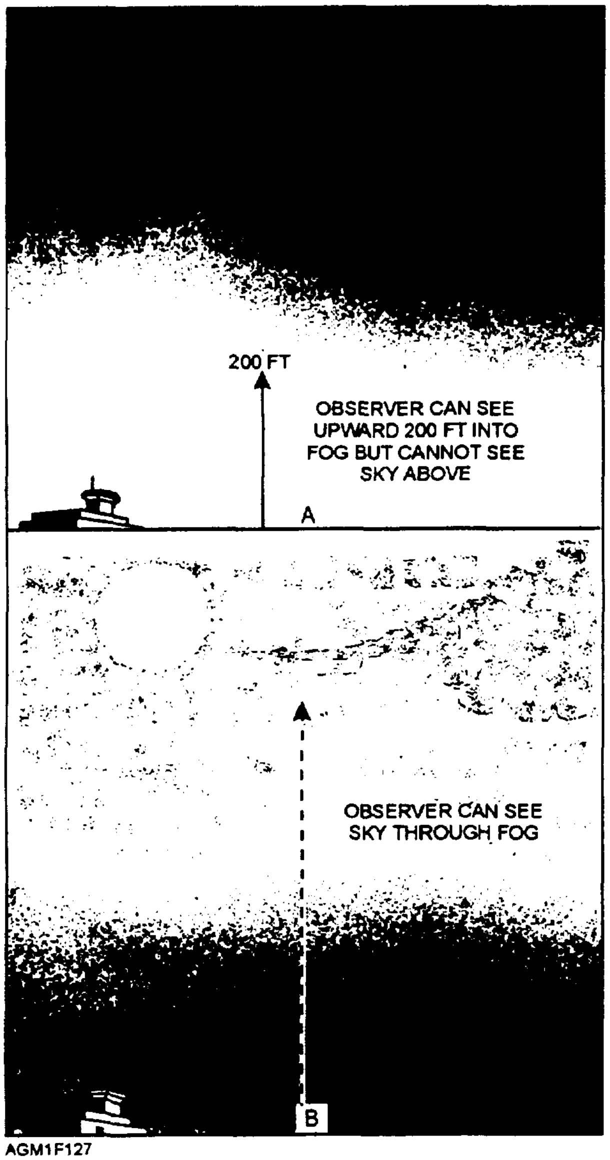

Figure 1-27.—Obscuration. (A) Total obscuration-sky completely hidden, (B) partial obscuration-higher cloud, sun, moon, or sky may be seen.

The best method to determine how much of the sky is hidden by a partial obscuration is to measure the elevation angle by using a clinometer (see chapter 2). The top of the partial obscuration is considered to be the point where the outline of higher clouds, the sun or the moon, or the light from stars is visible. Tables in NAVMETOCCOMINST 3141.2 and NAVMETOC-COMINST 3144.1 are used to convert elevation angle to eighths of sky coverage. Let's review a few of the important concepts involved when observing layer amounts.

When you are observing cumuliform clouds in a layer and blue sky is visible between the elements, the blue sky is not included as part of the layer coverage. For example, if many small cumulus clouds covered the sky from horizon to horizon, but the blue sky visible between each of the cloud cells is about the same size as the cloud cells, the layer coverage would only be 4/8. If however, the cumuliform cloud elements are joined by very thin cloud, even if the thin cloud is transparent and higher clouds can be seen through the thin cloud, the cloud layer is considered to cover the area. This is commonly the situation with altocumulus and cirrocumulus clouds. For example, if half of the sky is covered by a layer of altocumulus cloud with the denser cells being opaque, and the area between the cells is filled with a transparent cloud through which a very pale blue sky or higher clouds may be seen, the layer coverage is the same as the entire portion of the sky covered, or 4/8. The portion of a higher cloud layer visible through lower transparent clouds is treated as if it were not visible, that is, as if the lower cloud layer were opaque.

In a METAR/SPECI observation, when observing layers of clouds that are stacked on top of other layers, only count those clouds visible to you in the layer amount. If, for example, a layer of stratocumulus clouds covers half of the sky, and directly above the stratocumulus layer the observer can see only the edges of an altocumulus layer that seems to cover the same area as the stratocumulus layer, the most the observer could report is 4/8 stratocumulus and 1/8 altocumulus. Similarly, if an altocumulus layer covers 6/8 of the sky in a dense sheet, and 1/8 of cumulus is located below the altocumulus layer, the observer "knows" that the altocumulus layer covers the entire layer extending across 6/8 of the sky, even though 1/8 of the layer is hidden from view by the cumulus cloud. The cloud layers must still be reported as 1/8 cumulus and 5/8 altocumulus, since the observer cannot actually see the remaining 1/8 of altocumulus cloud. The maximum number of reportable layers is limited to six. OCONUS stations are limited to three reportable layers unless CB or TCU are present; in which case, a fourth layer may be reported.

Total Sky Coverage

To determine *total sky coverage,* simply add together the amount of clouds and/or obscurations in each layer. Total sky cover cannot exceed 8/8.

Summation Sky Coverage

Summation sky coverage is a concept used to determine cloud ceiling. Summation sky cover is determined for each layer of clouds by adding the coverage in the cloud layer to the coverage of all layers below it. In the example that follows, this has been done.

LAYER NUMBER	LAYER AMOUNT	SUM OF SKY COVER	SUMMATION LAYER COVER
1	1/8	1/8	FEW
2	3/8	4/8	SCATTERED
3	3/8	7/8	BROKEN
4	1/8	8/8	OVERCAST

Summation coverage for each layer is converted into plain language terms. They are *clear,* for no clouds present; few, for greater than 1/8 to 2/8; *scattered,* for 3/8 to 4/8 clouds; *broken,* for 5/8 to 7/8 clouds; and *overcast,* for 8/8 clouds, as shown in table 1-2. The term thin is not used in METAR/SPECI observations.

Table 1-2.—Cloud Ceiling Summation Coverage and Terms

Contraction	Meaning	T e x t T e x t
SKC	Sky clear	0/8
FEW	trace	>0/8-2/8
SCT	Scattered	3/8-4/8
BKN	Broken	5/8-7/8
OVC	Overcast	8/8
VV	Vertical Visibility	8/8

CEILING DETERMINATION

The terms *ceiling* and *cloud ceiling* are defined as the height-above-ground level of the lowest broken or overcast layer. If the sky is totally obscured, the height of the vertical visibility (VV) is used as the ceiling height. Table 1-2 relates the measurement of sky cover as observed in eighths, to the terms used to discuss sky cover and ceilings. In the example we just covered, the ceiling would be at layer No. 3, the broken layer.

In addition to determining layer amounts, total sky coverage, summation coverage, and the ceiling based on the summation coverage, you must also identify cloud layer heights and ceiling height.

CLOUD LAYER HEIGHTS/CEILING HEIGHT

The height must be determined for the base of all layers of clouds. The height for the lowest broken or overcast layer is used as the ceiling height. A surface-based obscuration also constitutes a ceiling; vertical visibility into the obscuration is used as ceiling height.

Cloud layer height and ceiling height may be determined by several methods. Estimation is the most frequently used method for cloud layer height. It is acceptable for determining heights of low scattered cloud layers or higher cloud layers. When the cloud layer forms a ceiling, especially if the layer height is below 3,000 feet, one or more of the more accurate methods should be used. The following list of cloud layer height determination methods is generally ordered from the most accurate to the least accurate:

- Measurement by comparison to known heights of structures or landmarks within 1 1/2 miles of the runway
- Measurement by ASOS or SMOOS cloud-height sensor
- Measurement by rotating beam ceilometer for heights less than 10 times the baseline
- Measurement by ceiling light and clinometer
- Estimation by rotating beam ceilometer for heights more than 10 times the baseline
- Estimation by pilot during ascent or descent
- Estimation by ceiling balloon
- Estimation by comparison to terrain or structures more than 1 1/2 miles from the runway
- Estimation by convective-cloud-height diagram
- Estimation using the Skew-T, Log P diagram
- Estimations from conventional weather/Doppler radar
- Estimation using other station reports in the vicinity
- Estimation by observational experience

Obviously, not all methods may be used at all times, and some methods work better than others in different situations. When a cloud layer height value falls halfway between two reportable valves, round down to the nearest reportable increment given in table 1-3.

Table 1-3.—Reportable Values for Cloud Layer Height and Ceiling Height

HEIGHT IN FEET	REPORTABLE VALUE
≤50	0
5,000 or less	Nearest 100 feet
5,001 to 10,000	Nearest 500 feet
Above 10,000	Nearest 1,000 feet

NAVMETOCCOMINST 3141.2 and NAVMETOCCOMINST 3144.1 discuss in detail the various methods and procedures used to determine cloud height and ceiling height.

REVIEW QUESTIONS

Q24. *How is the amount* of *cloud layer coverage and total sky coverage measured?*

Q25. *Define cloud layer.*

Q26. *Define cloud ceiling.*

Q27. *Define total obscuration.*

Q28. *Define summation sky coverage.*

Q29. *Given: Layer No.1 is 1/8 fog (SFC)*

Layer No.2 is 2/8 cumulus 3,000 ft

Layer No.3 is 2/8 altocumulus 12,000 ft

Layer No.4 is 5/8 cirrus 20,000 ft

What is the ceiling height?

Q30. *A cloud height* of *7,550 feet would be reported as what height?*

VISIBILITY

LEARNING OBJECTIVES: Describe prevailing visibility, sector visibility, and differing level visibility. Define runway visual range.

Visibility, as well as ceiling height, aids in decisions involving air traffic control. For this reason, the observation of visibility must be timely, accurate, and representative. There are four types of visibility that you must observe: (1) prevailing visibility, (2) sector visibility, (3) differing level visibility, and (4) runway visual range. Both NAVMETOCCOMINST 3141.2 and NAVMETOCCOMINST 3144.1 provide thorough and detailed guidance on visibility observations. Ashore, visibility is observed in statute miles. Aboard ship, visibility is observed in nautical miles. Observing stations located outside the United States report visibility in meters.

When observing visibility, you should note the distance as follows:

- To the nearest 1/16 mile when visibility is less than 3/8 mile
- To the nearest 1/8 mile when it is between 3/8 and 2 miles
- To the nearest 1/4 mile, between 2 and 3 miles
- To the nearest mile, from 3 to 15 miles
- In 5-mile increments, above 15 miles

When the visibility falls between two values, the lower value is always used. For example, a measured visibility of 3 3/4 miles is called "3 miles." See Appendix II of this module for a visibility conversion table.

PREVAILING VISIBILITY

Prevailing visibility is the greatest distance that known objects can be seen and identified throughout half or more of the horizon circle. The most reliable method for determining prevailing visibility is by the eye of a trained observer. The sensors provided with automatic observing systems provide only an approximation of prevailing visibility based on the sampling of obstructions-to-vision present in only a small area around the sensor. To aid in the determination of prevailing visibility, observation stations are required to maintain a visibility chart. The visibility chart identifies each daytime and nighttime visibility marker with direction and distance to the marker. Daytime markers are generally dark, prominent objects that stand out when viewed against the lighter sky. Nighttime markers are usually unfocused lights of moderate intensity, such as radio tower lights or channel marker lights.

At sea, since the ship is usually moving, fixed visibility markers are not available. The Combat Information Center (CIC), however, maintains tracks on other ships in the area, as well as coastal formations and prominent objects ashore. Coastal formations and prominent objects ashore may be used as visibility markers. Direct coordination between the observer and CIC is necessary to obtain timely and accurate distances to observable objects. This may be done through one of the Lookouts equipped with a sound-powered phone, on the "JL" circuit. All ships and most large coastal objects may also be used as distance markers at night; their navigation lights should be clearly seen. CIC will also be able to inform you of the probable light patterns and colors that various objects may be showing.

Radar returns from landmasses or isolated rain showers may also provide a valuable indication of visibility range. The distance to the horizon also plays an important part in visibility observations at sea. (The distance to the horizon in nautical miles is 1.15 times the square root of the height, in feet, of your eyes above the water.) From the deck of a small boat, the horizon is only about 3 nautical miles away. From ships with weather decks about 30 feet above the water, an observer sees the horizon at about 7 nautical miles. And from the flight deck of an aircraft carrier (average 65 feet above the water), a standing observer's eyes are about 70 to 71 feet above the water, and the horizon is seen at just under 10 nautical miles. These distances usually limit what an observer may be able to see. A table of the distance an object may be seen based on the height of the observer's eyes above sea versus the height of the object is provided in NAVMETOCCOMINST 3144.1.

In certain situations, prevailing visibility may fluctuate up and down during the observation period. In those cases, average visibility is used and is called *variable visibility.* The observer must note the lowest and highest visibility for entry on the observation record.

SECTOR VISIBILITY

A sector is any portion of the area surrounding the station out as far as the horizon. When the visibility surrounding the station is not uniformly equal in all directions and the difference is operationally significant, then each area with a different visibility is designated a sector. The size of the sector, extending in a pie-slice out from the observation point, is as large or as small as is required to describe the area affected by the different visibility, but must be limited to 1/8 (45°) of the horizon circle. Sector visibility is commonly used at air stations that have lakes, rivers, or swamps nearby, which favor fog development. Visibility in fog over a swamp area may, for example, be 3 miles, while the remainder of the area has 7 miles visibility in haze. Smoke and localized rain showers are other phenomena that commonly cause poorer visibility in a sector.

Once an area of lower or higher visibility is identified, the directions of the S-point compass (N, NE, E, SE, S, SW, W, and NW) are usually used to identify the sector. Each sector, using the 8-point compass, covers 45° of azimuth centered on the compass point identified.

Sector visibility is reported in the observation only when it differs from the prevailing visibility, and either the prevailing or sector visibility is less than 3 miles.

DIFFERING LEVEL VISIBILITY

Differing level visibility is any prevailing visibility observed from an elevation or location other than the official observation site. Differing level visibility is commonly evaluated from the aircraft control tower by certified tower visibility observers. In this case the prevailing visibility is usually called *tower visibility.* Tower visibility may differ from the airfield-level prevailing visibility based on the type of obstruction-to-vision present. Differing level visibility is only reported when the prevailing visibility is 4 miles or less.

RUNWAY VISUAL RANGE

The runway visual range, abbreviated RVR, is an instrument measurement of the distance the pilot can see down the runway as an aircraft touches down during landing. RVR is observed at shore stations using the AN/GMQ-32 transmissometer when the prevailing visibility or sector visibility falls below 2 miles, but is only reportable when the prevailing visibility is 1 mile or less or the RVR value for the runway is 6,000 feet or less. NAVMETOCCOMINST 3 141.2 further outlines procedures for reporting RVR.

When the prevailing visibility falls to less than 7 miles, the reason that the visibility is restricted must be noted in the observation. Any phenomenon that reduces visibility is called an "obstruction to vision." The occurrence of "weather," such as precipitation, also may reduce visibility. In the next section, we will cover weather and obstructions to vision.

REVIEW QUESTIONS

Q31. What are the four types of *visibility that may be observed?*

Q32. Define prevailing visibility.

Q33. Where can shipboard observers obtain visibility range information at sea?

Q34. When is sector visibility reported?

Q35. When is differing level visibility reported?

WEATHER AND OBSTRUCTIONS TO VISION

LEARNING OBJECTIVES: Identify six types of lithometeors. Compare the condensation/sublimation and precipitation forms of hydrometeors. Explain wind-blown forms of hydrometeors. Describe two types of electrometeors. Define and list four types of photometeors.

The occurrence of weather and the presence of obstructions to visibility are directly related to sky condition and the visibility. Observing the type of weather occurring and the presence of any obstructions to visibility is usually the third task undertaken in an observation. A pilot may use this information to determine the impact of the conditions at a station on the aircraft being flown. In this discussion, we use the term *weather* to refer to any particles suspended in or precipitating from the atmosphere, or to the process that causes these particles to precipitate from the atmosphere. Observable weather elements may be broken down into four groups: lithometeors, hydrometeors, electrometeors, and photometeors.

LITHOMETEORS

A *lithometeor* is any dry particle suspended in or falling from the atmosphere. The particles are usually formed on earth's surface and then are carried aloft by either wind or thermal currents. Haze, smoke, dust, dust-devils, ash, and sand are all lithometeors.

Haze

Haze is composed of suspended dust, plant pollen, or salt particles that are so small that they cannot be seen by the unaided eye. It is opalescent, reducing visibility. Haze typically produces a bluish tinge when viewed against a dark background. It produces a dirty yellow or orange tinge when viewed against a brighter background because of the scattering of light. When haze is present and the sun is well above the horizon, its light may have a silvery tinge. Haze particles are *hygroscopic*—they attract moisture. Because they attract moisture, they are good *condensation nuclei*. When conditions are favorable, haze may attract sufficient moisture to thicken into fog as the sun sets and the temperature drops.

Smoke

Smoke is composed of fine ash particles and other by-products of combustion. When concentrated at its source, smoke may appear white to bluish-black, or yellow to brown, depending on its composition and the amount of water vapor present. After it is dispersed in the atmosphere, smoke is distinguished from haze by its characteristic reddish tinge, especially near the horizon at sunrise and sunset.

Dust

Dust is composed of fine solid matter uniformly distributed in the air. It typically imparts a tan or gray hue to distant objects. The sun's disk may appear pale and colorless, or may have a yellow tinge when viewed through dust. Although dust and haze appear similar, when the visibility is less than 7 miles, dust may be differentiated from haze or fog by the low relative humidity associated with dusty conditions. In certain areas of the world, suspended dust may reduce visibility to less than a mile. Normally, the lower visibility associated with dust is limited to *blowing dust*—dust picked up and carried by the wind. The term *dust storm* usually refers to blowing dust reducing visibility to 5/16 to 5/8 of a mile, while the term *heavy* or *severe dust storm* is reserved for use with blowing dust that restricts visibility to less than 5/16 mile.

Dust/Sand Whirl

Dust/sand whirls or *dust devils,* are rotating columns of dust or sand-laden air, caused by intense solar radiation. They are best developed on calm, hot, clear afternoons and in desert regions. Warm, ascending air in a dust devil may carry leaves and other small debris to a height of a few feet or a few hundred feet.

Ash

The phenomenon called *ash* in a surface meteorological observation usually refers to the heavier volcanic ash particles falling from a volcanic cloud. It may also be used to identify heavier solid particles precipitating and falling from an industrial smoke plume, the smoke from a forest fire, or the debris falling from a nuclear mushroom cloud.

Sand

Sand particles may be picked up from dry surfaces by the wind at wind speeds as low as 21 knots and carried to moderate heights. Stronger winds may carry sand to extreme heights. The term *sand storm* refers to blowing sand that reduces visibility from 5/16 to 5/8 mile, while the term *heavy or severe sand storm* means that visibility is less than 5/16 mile.

The only hazard to aviation caused by haze and smoke is reduced visibility. But dust, ash, and sand can also clog engine intakes and be very abrasive to moving components. Aircraft flying through these conditions may experience fatal engine failure.

HYDROMETEORS

Hydrometeors are liquid or solid water particles falling through, suspended in, or condensing/subliming from the atmosphere, as well as solid or liquid water blown from the surface by wind. The term refers to all forms of condensation, such as clouds, fog, dew, and frost; all forms of precipitation, such as rain, drizzle, snow and hail; and all forms of moisture blown about by the wind.

Condensation/Sublimation Forms

Many of the weather elements identified as hydrometeors are formed by the condensation or sublimation of water vapor in the air or on surfaces. Clouds and fog are hydrometeors of suspended liquid or solid moisture suspended in the air. Dew and frost are hydrometeors of moisture that condense or sublime directly on surfaces or on the ground.

CLOUDS.—Clouds are the visible form of water vapor, and consist of minute suspended droplets of liquid water or ice particles. Fog is a cloud on the earth's surface. Liquid water droplets develop from gaseous water vapor by the process of condensation. Solid water particles or ice crystals develop by the process of sublimation. During sublimation, gaseous water vapor bypasses the liquid state and goes directly from a gas to a solid, thereby releasing heat into the atmosphere. Three factors are necessary for cloud formation: sufficient moisture, hygroscopic nuclei, and a cooling process.

Moisture is supplied by evaporation and is distributed vertically by convection currents and horizontally by winds.

Hygroscopic nuclei are small particles on which water vapor can condense or sublime. Hygroscopic nuclei actually attract water vapor. The most effective hygroscopic nuclei are the by-products of combustion, sulfuric acid and nitric acid particles, and salts (such as sodium chloride raised from the sea surface). Dust particles may contain sufficient salts or acids to become hygroscopic nuclei, but dust particles in general are not effective hygroscopic nuclei. The presence of hygroscopic nuclei is a must for water vapor to condense. Air has been super-saturated in laboratories to over 400% before condensation began in the absence of hygroscopic nuclei. In actual conditions, in the presence of abundant hygroscopic nuclei, condensation may begin at relative humidities near 70%. Saturation of the air is reached when the relative humidity reaches 100%. At this point, the evaporation rate from liquid water droplets to water vapor equals the condensation rate from water vapor to liquid water, or theoretically, the sublimation rates from gas-to-solid and from solid-to-gas are exactly equal.

Hygroscopic nuclei are also called *condensation nuclei* and *sublimation nuclei* when referring to the specific process of condensation or sublimation.

A *cooling process* aids in condensation, since it increases the humidity of the air without increasing the amount of water vapor present. The higher the humidity, the easier condensation proceeds. The cooling process most frequently associated with condensation is *adiabatic expansion.* When a parcel of air is lifted higher in the atmosphere (where the pressure is lower), it expands and its temperature decreases. Another important cooling process is radiational cooling. Simply put, as the sun goes down, the air cools because the heat source, the sun, is no longer available to maintain the heating.

FOG.—Fog is a suspension of small visible water droplets (or ice crystals) in the air that reduces horizontal and/or vertical visibility at the earth's surface. Fog is a stratus cloud on the surface of the earth. It is distinguished from smoke, haze, or dust by its dampness and gray appearance. Fog usually does not form or exist when the difference between the air temperature and the dew-point temperature is greater than 4 Fahrenheit degrees (2 Celsius degrees). However, at temperatures below -2O°F (-29°C), *freezing fog,* or ice fog, may form when the dew-point temperature is as much as 8°F (4 Celsius degrees) lower than the air temperature. Freezing fog is composed entirely of ice crystals that sparkle brilliantly in light. When the air temperature is between 32°F and -20°F, fog may exist as super-cooled liquid droplets. This situation may produce delicate needle or platelike ice crystals on exposed surfaces, *known* as *hoarfrost. Rime ice,* a smooth, milky, white ice coating, or *glaze ice*, a smooth coating of clear ice, may also be produced by fog when the temperature is below freezing.

Fog is sometimes identified by the physical process by which it forms. Examples are *radiation fog*, formed by radiational cooling; *advection fog,* formed by moist air moving over a cooler surface; *steam fog,* formed when cold air moves over a warm body of water; *upslope fog,* caused by air cooling as it rises up a hill or mountain; and *frontal fog,* formed by the evaporation of rain in a colder air mass. You will study these later in preparation for AG2. To observe the presence of fog, you need not know how fog forms-only if it is present. The terms used to record fog that you, as the observer, must be familiar with are as follows:

- *Fog*—The vertical depth of fog is greater than 20 feet and the prevailing visibility is reduced to less than 5/8 mile (1,000 meters OCONUS).

- *Mist*—A fog condition that reduces prevailing visibility to between 5/8 mile (1,000 meters) and 6 miles (9,000 meters). The vertical depth of mist is greater than 20 feet.

- *Ground fog*—This term applies to fog that has little vertical extent, i.e., normally greater than 6 feet but less than 20 feet. This is a local phenomenon, usually formed by radiational cooling of the air. Ground fog can further be described as shallow, partial, or patchy.

- *Shallow fog*—This descriptor of fog applies to ground fog that covers the station and visibility at eye level is 7 miles or more, but the apparent visibility in the fog layer is still less than 5/8 mile. Shallow fog does not extend above 6 feet.

- *Partial fog*—This descriptor of fog applies to ground fog that covers a substantial part of the station and visibility in the fog is less than 5/8 mile, and visibility over the uncovered parts of the station is 5/8 mile or more. The vertical extent ofpartial fog is greater than 6 feet but less than 20 feet. This type of ground fog may be coded even when the prevailing visibility is 7 miles or more.

- *Patchy fog*—This descriptor of fog applies to ground fog that covers portions of the station, the apparent visibilty in the fog patch or bank is less than 5/8 mile, and visibility over the uncovered portions of the station is 5/8 mile or greater. The vertical extent of patchy fog is greater than 6 feet but less than 20 feet. This type of ground fog may be coded even when the prevailing visibility is 7 miles or greater.

DEW.—*Dew* is moisture that condenses directly on surfaces. Dew will form during the evening or late at night, usually when the winds are light. After the sun sets, the ground and objects near the ground cool by radiational cooling; they radiate heat energy as infrared radiation. When the ground or objects cool to the *dew-point temperature,* water vapor condenses out of the air onto the object's surface. *White dew* is dew that has frozen after the water condenses. It is recognizable as small beads or a beaded layer of clear ice, or sometimes milky-colored ice on surfaces.

FROST.—*Frost* is a layer of milky white ice crystals that sublime directly on the ground or on other surfaces. The crystals are commonly in the shape of needles, scales, feathers, or fans. Frost forms when radiational cooling lowers the temperature of objects below the freezing level. Since many objects cool faster than the air surrounding the objects, frost may form with ambient air temperatures above freezing, as high as 37°F. For frost to form, the object must be cooled to the *frost-point temperature,* which is also referred to the "dew-point temperature with respect to ice." This is the dew-point temperature calculated on the "low temperature" side of the Psychrometric Computer. Thicker deposits of needle or platelike frost, up to several inches thick, form in fog with ambient air temperatures below freezing. This form of frost is known as *hoarfrost.*

REVIEW QUESTIONS

Q36. What type of lithometeor produces a yellow or orange tinge when viewed against a brighter background?

Q37. Where are dust/sand whirls most likely to develop?

Q38. What does the term "heavy sandstorm" mean?

Q39. Define sublimation.

Q40. What three factors are necessary for cloud formation?

Q41. Fog may form when the temperature-dewpoint spread is how many Celsius degrees?

Q42. Fog formed by moist air moving over a cooler surface is known by what term?

Q43. Define the term "mist."

Q44. Explain the formation of frost.

Precipitation Forms

Precipitation includes all forms of moisture that fall to the earth's surface, such as rain, drizzle, snow, and hail. Precipitation is observed and classified by form, type, intensity, and character.

PRECIPITATION FORM.—*Precipitation form* is the state that the moisture is in: liquid, freezing, or *frozen. Liquid precipitation* is any precipitation that falls as a liquid and remains liquid after striking an object, such as the earth's surface or the skin of an aircraft. Rain and drizzle are the only two types of liquid precipitation.

Freezing precipitation is any precipitation that falls as a liquid and freezes upon contact with an object, such as freezing rain or freezing drizzle. In this form of precipitation, the liquid water may be a *super-cooled* liquid and freeze upon contact with an object, or the water droplet may have an above freezing temperature and freeze upon contact with an object that has a temperature below freezing. (Super-cooled liquids have a temperature below their normal freezing temperature, but still exist in the liquid state.) Small freezing drizzle particles form a milky white ice coating, typically referred to as *rime ice,* especially on aircraft in flight. Larger freezing drizzle and freezing rain drops form a transparent ice coating known as *clear ice* on aircraft in flight or as *glaze ice* on the ground, power lines, or trees.

Frozen precipitation is any precipitation of water that falls in its solid state, such as snow, hail, or ice pellets. Different forms of precipitation may occur together, such as mixed rain and snow; but such an occurrence is simply a mixture of forms, not a separate form of precipitation.

PRECIPITATION TYPE.—*Precipitation type* is the term used to identify various precipitation. Discussion of the types of precipitation follows:

- *Rain*—Liquid precipitation that has a water droplet diameter of 0.02 inch (0.5 mm) or larger. If the water droplets freeze upon contact with a surface, the phenomenon is called *freezing rain.*

- *Drizzle*—Liquid precipitation that consists of very small and uniformly dispersed droplets of liquid water that appear to "float" while following air currents. Drizzle usually falls from low stratus clouds and is frequently accompanied by fog. A slow rate of fall and the small size of the droplets (less than 0.02 inch) distinguish drizzle from rain. When drizzle freezes on contact with the ground or other objects, it is referred to as *freezing drizzle.* Drizzle usually restricts visibility.

- *Snow*—Precipitation that consists of white or translucent ice crystals. In their pure form, the ice crystals are highly complex, hexagonal, branched structures. Snow falls as a combination of individual crystals, fragments of crystals, or clusters of crystals. Warmer conditions tend to favor larger crystal sizes and clusters of crystals. Snow must form in cloud temperatures below freezing, though it may fall through air at above freezing temperatures for a short period of time before melting.

- *Snow Pellets/Small Hail*—White, opaque, round (or occasionally conical) kernels of snowlike consistency, 0.08 to 0.2 inch in diameter. They are crisp, easily compressible, and may rebound or burst upon striking a hard surface. Snow pellets occur almost exclusively in snow showers.

- *Snow Grains*—Very small, white, opaque grains of ice similar in crystal structure to snow. Whereas the crystal structure of snow has very fine, needlelike branches, the crystal structure of snow grains has thicker, denser elements, with the space between hexagonal branched commonly completely filled. Snow grains do not bounce or shatter on hard surfaces. They usually fall in small quantities, mostly from stratus clouds and never as showers.

- *Ice Pellets*—Transparent or translucent particles of ice that are either round or irregular (rarely conical) and have a diameter of 0.2 inch or less. They usually rebound upon striking hard surfaces and make a sound upon impact. The term *ice pellets* describes two different types of similar looking solid precipitation. One type is composed of hard grains of ice formed from freezing rain or the refreezing of melted snowflakes. It falls as continuous precipitation and is sometimes referred to as *sleet.* Another type is composed of pellets of snow encased in a thin layer of ice. It is formed from the freezing of water droplets intercepted by snow pellets or by the refreezing of a partially melted snow pellet. This type falls as showery precipitation and is usually associated with thunderstorms.

- *Hail*—A clear to opaque ball of hard ice, ranging in diameter from 1/8 inch or so to 5 inches or larger. Hailstone size is measured and reported in inches, but hailstones are usually compared to common objects when reported to the public by television or radio, such as pea size, walnut size, golf-ball size, baseball size, or softball size. Hail frequently displays a layered appearance of alternate opaque and clear ice. It is produced only in thunderstorms, but may be ejected from the top or sides of a thunderstorm to fall and strike the ground without a cumulonimbus cloud directly overhead.

- *Ice crystals*—Tiny unbranched crystals of ice in the form of needles, hexagonal columns, or plates. They are often so small that they may be suspended in air and are sometimes referred to as diamond dust. Ice crystals are visible mainly when they glitter in the sunlight or in spotlights at night. Although common in polar regions, this phenomenon occurs only during very cold temperatures in stable air masses. Ice crystals may fall from any type of cloud or from clear air. As moist air cools below -40°F, the water vapor may sublime directly to form ice crystals, and precipitate, without ever forming a cloud.

PRECIPITATION INTENSITY.—*Precipitation intensity* is an approximation of the rate of fall or the rate of accumulation of precipitation. During an observation, intensity for each type of precipitation (other than hail and ice crystals) must be determined. NAVMETOCCOMINST 3141.2 and NAVMETOCCOMINST 3144.1 provide valuable information on determining intensity by visibility, accumulation rate, size of the rain drops, sound on the roof, height of splashes, and the rate at which puddles form. The primary indicator for snow and drizzle is visibility. Table 1-4 summarizes the indicators to aid in your understanding of the term *precipitation intensity.*

Direct observation is the best method of determining the type of precipitation occurring. However, in chapter 2, you will study observation equipment that provides valuable indicators of precipitation intensity.

PRECIPITATION CHARACTER.—*Precipitation character* is a term used to describe how precipitation falls. Three terms are used to describe character: *continuous, intermittent,* and *showery. The* term *continuous precipitation* means that the precipitation falls for a long period of time over a specific area. When the system producing the precipitation is moving, use of the term implies that the area covered by the rain is extensive. Continuous precipitation falls from stratiform clouds, especially nimbostratus. Continuous precipitation changes intensity only slowly, and may be of light or moderate intensity, rarely heavy. When used alone, the terms *rain, drizzle,* and snow refer to either continuous or intermittent precipitation.

The term *intermittent precipitation* is used to describe precipitation that occurs for brief periods of time (lasting less than 1 hour). Intermittent precipitation changes intensity slowly, and is usually light. Although the overall area affected by intermittent precipitation is usually very large, at any given time only a portion of the area is actually receiving precipitation. Like continuous precipitation, intermittent precipitation usually falls from stratiform clouds, especially nimbostratus.

Sudden starting or stopping ofprecipitation or rapid changes in the intensity of precipitation indicate *showery precipitation.* Showery precipitation, or showers, fall from cumuliform clouds, especially cumulonimbus. Showers cover only a relatively small area at a given time, and, unless the cumuliform cloud is stationary, showers last only a brief time before moving on. Rain falling from cumuliform clouds is called a "rain shower," and a cumuliform shower of snow is called a "snow shower." The public popularly calls a very light snow shower "snow flurries."

PRECIPITATION THEORY.—Several valid theories have been formulated in regard to the growth of raindrops. The theories most widely accepted today are treated here in a combined form.

It is believed that most precipitation in the mid- and high-latitudes starts as ice crystals. The crystals melt and fall as liquid precipitation only when it passes through an above-freezing stratum of air. Due to the low freezing level in these regions, the abundance of water vapor in the atmosphere is found at, near, or below freezing temperatures. In clouds below freezing temperatures, water coexists in all three states: solid, liquid, and gas. Both solid and liquid particles are present within most clouds. The higher vapor pressure for the liquid droplets compared to the low vapor pressure for the solid ice crystals tends to cause a net evaporation of gaseous water from the liquid droplets. In turn, there is a corresponding net sublimation of the gaseous vapor on to the solid ice crystals. This tends to retard the growth of the liquid drops while aiding the growth of the crystals. When the ice crystals become too large (too heavy) to remain suspended in the atmosphere, they fall as precipitation.

In the low-latitudes (tropics) and much of the mid-latitudes during the warmer months, the freezing level in the atmosphere is generally much higher. The abundance of moisture in the above freezing portions of the lower atmosphere allows the majority of the precipitation to form initially as liquid water droplets.

Table 1-4.—Precipitation Intensity Indicators

TYPE	LIGHT	MODERATE	HEAVY	
Rain, Snow Freezing rain	trace to 0.10" trace to 2.5 mm	0.11" to 0.30" 2.8 mm to 7.6 mm	>.30" >7.6 mm	**ACCUMULATION PER HOUR**
Drizzle	trace to 0.01" trace to 0.3 mm	>0.01" to 0.02" >0.3 mm to 0.5 mm	>0.02” >0.5 mm	
Rain, Snow Freezing rain	trace to 0.01" trace to 0.3 mm	>0.01" to 0.03" >0.3 mm to 0.8 mm	>0.03” >0.8 mm	**ACCUMULATION PER 6 MINUTES**
Ice pellets	Little/none	Slow	Rapid	**ACCUMULATION**
Drizzle, Snow grains, Snow pellets and snow	2 5/8 mi 2 0.55 nm 2 1,000 m	5/16 to ≤1/2 mi 0.25 to 0.50 nm 500 to 1000 m	≤ 1/4 mi ≤ 0.20 nm ≤ 400 m	**VISIBILITY**
Rain	Easily seen	Not easily seen	Unidentifiable Rain in sheets	**DROPLET IDENTIFICATION**
Rain	Hardly noticeable	Noticeable	Heavy, several inches high	**SPRAY OVER HARD SURFACES**
Rain	Forms slowly	Forms rapidly	Forms very rapidly	**PUDDLES**

After rain droplets and/or ice crystals form, growth in size is aided by the process of *accretion*—the fusing together of small droplets that collide. Droplets may also collide with ice crystals and freeze upon contact to make a larger crystal. Turbulence within a cloud may increase the rate of accretion, while strong updrafts within cumulus clouds may keep the crystals or droplets, which are continuously increasing in size, suspended for longer periods of time and allow the growth of very large drops or crystals. Chapter 9 of the text *Meteorology Today* contains more detailed information on precipitation processes.

Wind-blown Forms

A few reportable hydrometeors are simply moisture picked up from the ground or ocean surface and carried by the wind. Blowing and drifting snow, dust, sand, and blowing spray are hydrometeors of this group.

BLOWING SNOW/DUST/SAND.—The hydrometeor *blowing snow, dust, or sand* exists only when strong winds lift snow, dust or sand from the surface to a height of 6 feet or greater, and the snow, dust, or sand reduces the visibility to less than 7 miles.

LOW DRIFTING SNOW/DUST/SAND.—This phenomena exists only when strong winds lift snow, dust, or sand from the surface to *less* than 6 feet, and the snow, dust, or sand *does not* reduce the visibility below 7 miles.

BLOWING SPRAY.—A hydrometeor that occurs only in very high winds, where water is lifted from the ocean by the wind and reduces visibility at eye level to 6 nautical miles or less.

ELECTROMETEORS

Our discussion includes lightning and auroras, which are the only significant electrometeors.

Lightning

Lightning is the most frequently observed electrometeor. This massive electrical discharge from rapidly growing cumuliform clouds is a very dangerous phenomenon that kills an average of 85 people per year, injures hundreds of people per year, and causes property damage in the millions of dollars. For example, in 1989 over $72 million in civilian property damage was caused directly by lightning.

The vast majority of lightning discharges jump from cloud to cloud, and are abbreviated on observations as LGTCC. A smaller number of discharges appear to occur entirely within a single cloud (LTGIC) or from a cloud to the surrounding clear air (LTGCA). Only a small percentage of lightning discharges occur from cloud to ground (LTGCG) (fig. 1-28). Cloud-to-ground lightning may strike up to 12 miles from the rainfall area in a thunderstorm (fig. 1-29).

Other rarer forms of lightning are ball lightning or St. Elmo's Fire, and lace lightning. Ball lightning appears as ball-shaped parcels of brightly glowing electricity; it may be stationary on a sharp object such as an antenna, mast, or the ridge of a roof; or it may be falling, rolling across a surface, or even bouncing over the ground. Different reports state ball lightning may penetrate windows or wooden walls with little or no trace of passage, while others attribute great damage to ball lightning contact. Ball lightning has been reported to explode in a shower of sparks upon contact with stationary objects.

Lace lightning is occasionally seen moving across the sky through a heavy cirrus spissatus cloud layer well downstream of larger thunderstorms. It appears to move across the sky in pulses forming a fine weblike or lacelike network through the cirrus cloud.

In surface aviation weather observations, thunderstorms are considered to have begun when the first thunder is heard or when overhead lightning is observed, and the local noise level is high enough as might prevent the observer from hearing thunder. Direction, estimated distance to the leading edge of the storm, and direction of movement should be noted if possible. As the storm gets closer, the types of the lightning discharges should be noted, along with the frequency of the lightning discharges, such as occasional lightning or frequent lightning. The Lightning Detection and Tracking System (LDATS) equipment in use at several Navy and Marine Corps weather offices will assist the observer in determining distance, direction, and speed of movement of thunderstorms. Many stations have requirements to set thunderstorm conditions to warn base personnel of anticipated or impending thunderstorm activity. The observer’s input as to the existence of thunderstorms, their location, and movement is critical to the thunderstorm warning system.

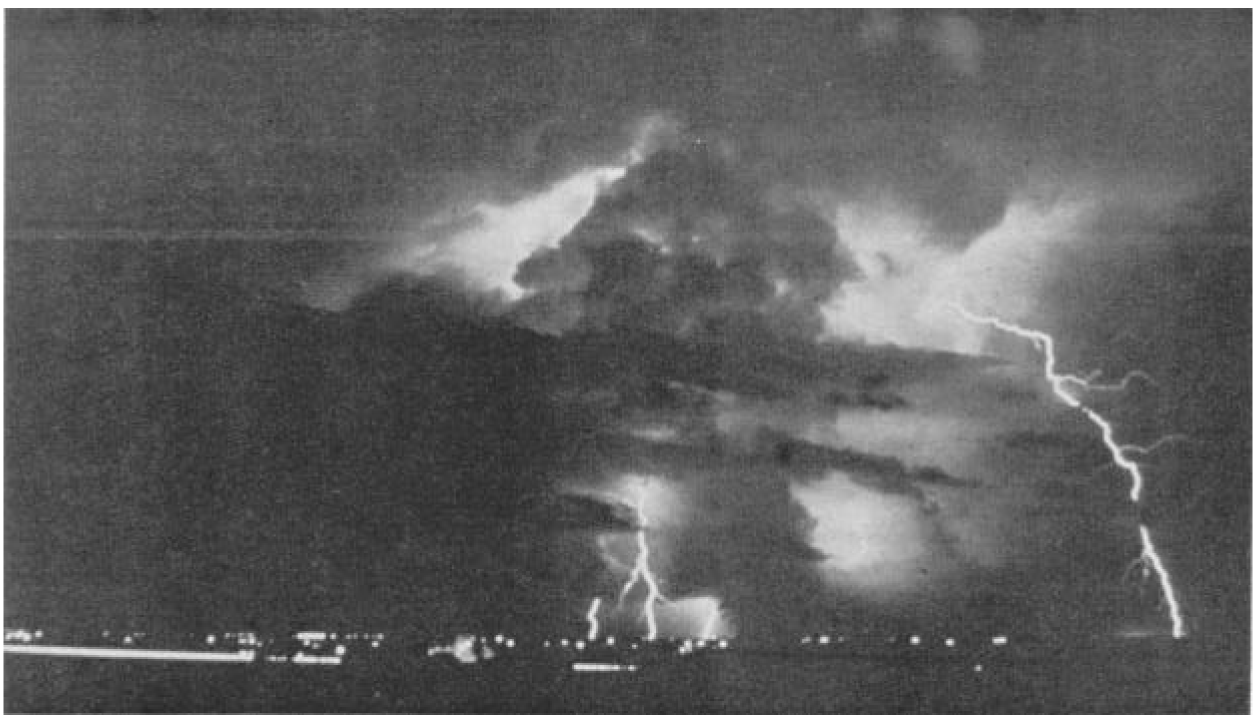

Figure 1-28.—Cloud-to-ground lightning under a cumulonimbus cloud base.

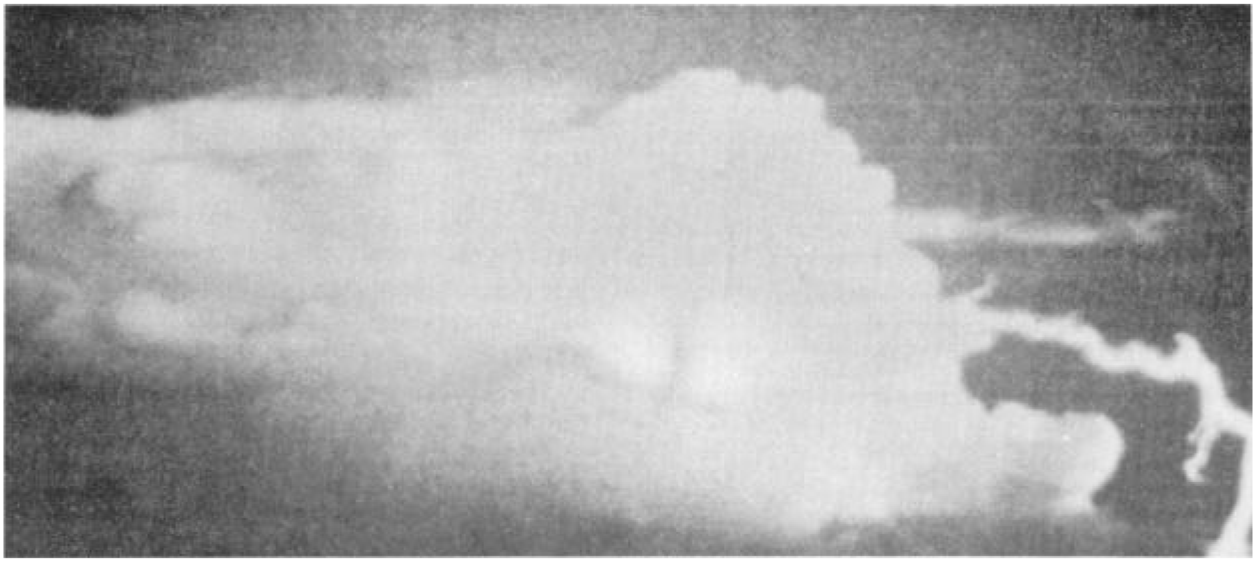

Figure 1-29.—Cloud-to-ground lightning from the side of cumulonimbus calvus cloud to ground several miles from the cloud base.

Auroras

Auroras are luminous phenomena that appear in the high atmosphere in the form of arcs, bands, draperies, or curtains. These phenomena are usually white but may have other colors. The lower edges of the arcs or curtains are usually well defined; the upper edges are diffuse. Polar auroras are caused by electrically charged particles ejected from the sun that act on the rarified (select) gases of the upper atmosphere. The particles are channeled by earth's magnetic field, so auroras are concentratednear the magnetic poles. In the Northern Hemisphere, they are known as the Aurora Borealis, while in the Southern Hemisphere they are known as the Aurora Australis. Another form of the aurora is *airglow*. Airglow is fainter and lacks definition, but may be seen in the low and middle latitudes as a faint glow in the sky. Unless remarkably intense or vivid, auroras are not reported in surface aviation observations. Shipboard observers will only report auroras when located north of 45" north latitude or south of 45" south latitude.

PHOTOMETEORS

Photometeors consist of a number of atmospheric phenomena attributed to the reflection or refraction of visible light in the sky by liquid water droplets, ice crystals, by the air itself, or by solid particles in the air, such as volcanic ash or dust. Several types of photometeor phenomena may be used to assist in the identification of cloud type, such as the halo, corona, irisation, and rainbows. Fogbows are classified as photometeors, as are superior mirages (objects such as buildings, trees, or mountains seen inverted in the sky) and inferior mirages (shimmering wet appearance of hot surfaces such as roads or sand). Other than aiding in the identification of other phenomena, these phenomena are not significant in surface aviation weather observations; therefore, they are not reported.

Of the weather elements we have discussed to this point, most of the identification of the phenomena is based on the observer's knowledge and on what the observer sees directly. Sure, instruments are in use to help the observer determine visual range and cloud height, but the only method to determine cloud type and what type of weather is occurring is by the observer's classification. Many of the remainder of the observable elements for a surface aviation weather observation are directly obtainable from instruments, so our explanation should be somewhat easier for the remainder of the chapter. Let's continue with the next section on observing the pressure.

REVIEW QUESTIONS

Q45. Any liquid that has a temperature below its normal freezing point but still exists in the liquid state is known by what term?

Q46. What distinguishes drizzle from rain?

Q47. What type of hydrometeor is composed of hard grains of ice formed from freezing rain or the refreezing of snowflakes?

Q48. If rain is accumulating at a rate of 0.25 inches per hour, how should the intensity be classified?

Q49. What does the abbreviation LTGCA mean?

Q50. When is a thunderstorm considered to have begun?

PRESSURE

LEARNING OBJECTIVES: Recognize the importance of an accurate pressure observation. Describe atmospheric pressure, barometric pressure, and station pressure. Explain sea-level pressure and altimeter setting. Define pressure tendency.

Pressure is an important weather analysis and forecasting item used by agriculturalists, pilots, and weather forecasters. Many years ago, farmers discovered that falling atmospheric pressure is associated with poor, unsettled weather and that fair weather is associated with rising atmospheric pressure. Today, most farmers rely on scientific forecasts to regulate their activity. Overland, at and below 18,000 feet, pilots fly aircraft at their assigned flight levels based on the altimeter setting provided by local weather-observation stations.

In forecasting, pressure is used to analyze the *isobar* patterns, or lines of equal pressure. From the isobar patterns, analysts can determine wind speeds, centers of high and low pressure, and other critical information. By tracking the movement of high- and low-pressure centers, forecasters may anticipate future movements of the centers, and their associated weather patterns.

For pressure values to be meaningful to pilots, analysts, and forecasters, the reported readings must be accurate. An error in a reported sea-level pressure may cause an analysis to be in error, especially over data-sparse areas, such as the oceans. But an error in an altimeter setting can be disastrous for a pilot. The responsibility for observing, calculating, and reporting pressures accurately rests solely on you, the weather observer.

In this section, we cover the different types of pressure that must be observed, associated pressure terms, and the pressure values that must be calculated for an observation.

The standard units used to measure and report pressure values are inches of mercury and hectopascals. The term *hectopascals (hPa)* replaced the term *millibars (mb)* several years ago. A hectopascal is exactly equal to one millibar. See Appendix II for conversions between inches of mercury and hectopascals.

ATMOSPHERIC PRESSURE

Atmospheric pressure refers to the pressure exerted by the column of air on any point on the earth's surface. The term is not specific as to where the point in question is located. The vagueness of the term causes some confusion in military weather because the observer can never be sure if the person asking for atmospheric pressure wants station pressure, sea-level pressure, or even an altimeter setting.

BAROMETRIC PRESSURE

Barometric pressure is the pressure read directly from a precision aneroid barometer or a tactical aneroid barometer. On the ML-448/UM precision aneroid barometer, this value may be read in inches or in millibars. Readings in millibars can be converted directly to hectopascals; for example, 978.7 millibars equals 978.7 hPa.

STATION PRESSURE

Station Pressure is the pressure value read on the barometer (barometric pressure in inches or hectopascals) corrected for the difference between the height of the barometer and the station elevation. The correction that is added to the barometric pressure may be an instrument correction, a removal correction, and a temperature correction.

- The *station elevation* is the height of the highest point on the runway above mean sea level (MSL). This is the height that is found published in the Flight Information Publications. Aboard naval ships, the station elevation is considered to be the height of the barometer above the water line, not the height of the flight deck.

- The instrument correction (if used) is determined by the barometer calibration facility during the required semiannual calibration.

- The *removal correction* is the pressure correction based on the difference in height (in feet) of the barometer and the runway or station elevation. To find the removal correction (inches of mercury), multiply the difference in height in feet by 0.001 inch of mercury per foot. The correction in hectopascals is found by multiplying the difference in feet by 0.036 hectopascals per foot. The removal correction is added to the barometric pressure if the barometer is higher than the runway, and subtracted if the barometer is lower than the runway. Once determined, the same removal correction is always added to the indicated barometric pressure unless the barometer is moved.

Aboard naval ships, since the station elevation is the height of the barometer, no removal correction is added when determining station pressure. Temperature corrections are required only for barometers used outdoors.

Station pressure is calculated to the nearest 0.005 inch, or 0.1 hPa. When requested or given in a radio conversation, station pressure is identified with the Q-signal *QFE.*

SEA-LEVEL PRESSURE

Sea-level pressure is a theoretical pressure at the station if the station were actually at sea level. It is calculated on a CP-402/UM pressure reduction computer by using station pressure and an "r" factor that must be obtained from a table.

The "r" factor is based on station elevation and is determined by station temperature. These "r" factors are based on a complex series of calculations found in the *Manual of Barometry,* NAVWEPS 50-1D-510. Tables of "r" values for each station are available from FNMOD Asheville, North Carolina.

Some Navy and Marine Corps weather stations are authorized to use a *constant additive correction* to reduce station pressure to sea-level pressure. Sea-level pressure is always higher than the station pressure with the exception of stations located below sea level (for example, a station located in Death Valley, California, at 280 feet below sea level). A constant additive correction factor (for example, +0.017 inch) for a particular station would be added to the station pressure (in inches) every time a sea-level pressure is required. Authorized shore stations are assigned a constant additive correction factor by FNMOD Asheville.

Since the height of shipboard barometers changes, depending on the load the ship is carrying, shipboard corrections for sea-level pressure are found by multiplying the height of the barometer above the water line in feet by 0.001 inch of mercury per foot (to obtain a correction for inches of mercury) or by 0.036 hectopascals per foot (to obtain a correction for the millibar or hectopascal scale readings). The corrections are then added to the station pressure.

Commonly abbreviated "SLP," sea-level pressure is identified in radio conversations by the Q-signal *QFF.* Sea-level pressure is normally calculated to the nearest 0.1 hPa.

ALTIMETER SETTING

Altimeter setting is a simplified sea-level pressure in inches that may be "dialed" into an aircraft's altimeter so that the altimeter will indicate the correct elevation above mean sea level of an airfield or flight deck when the aircraft's wheels are on the runway or flight deck.

Commonly abbreviated *ALSTG,* altimeter setting is identified in radio conversations by the Q-signal *QNH.* For example, a pilot requesting altimeter setting over the radio should say "What is QNH?" The answer would be "QNH Three Zero Point Zero Two Inches" if the altimeter setting were 30.02 inches.

Weather observers should not underrate the importance of the altimeter setting. Many aircraft accidents have been caused by faulty settings. Altimeter settings are computed for all surface aviation observations with the exception of single-element specials, and must be determined with extreme care.

Altimeter setting is computed using station pressure and a pressure reduction computer. Unlike sea-level pressure (computed on the opposite side of same instrument), the altimeter setting is computed using only the station elevation and station pressure as arguments, and the setting is read to the nearest 0.01 inch.

Altimeter settings may also be obtained from a Digital Altimeter Setting Indicator or an Automated Surface Observing System (ASOS), as you will see in the chapter on equipment.

NOTE: Many years ago, altimeter settings were calculated from the runway elevation (station elevation) plus 10 feet, to compensate for the average height of the altimeter instrument above the wheels of an aircraft.

This practice is no longer followed. Additionally, sea-level pressure should not be converted from hectopascals into inches for use as an altimeter setting, since differences in such calculations could yield false altimeter settings.

Aircraft flying above 18,000 feet overland and on over water flights more than 100 miles offshore routinely use the standard pressure, 29.92 inches, as an altimeter setting. During low-level tactical flights and landings aboard aircraft carriers, however, accurate altimeter settings are required. Now let's consider pressure tendency.

PRESSURE TENDENCY

The *pressure tendency* is the net change in the barometric pressure during a period of time and the trend or characteristic of the change. Normally the pressure tendency is observed for 3-hour periods ending at the intermediate synoptic times 0000Z, 0300Z, 0600Z, etc. Pressure tendencies for 12- and 24-hour periods may also be observed, and routinely replace the 3-hour pressure tendencies in observations taken in the tropics.

The net change is determined by taking the difference in the station pressure between the current observation and the station pressure 3, 12, or 24 hours ago. The trend or characteristic is determined from the barograph trace, or the actual recorded station pressures during the period. The general trends of pressure "higher," the "same," or "lower" than at the beginning of the period are further described in both NAVMETOCCOMINST 3 141.2 and NAVMETOCCOMINST 3144.1 for reporting purposes.

We will discuss some related pressure calculations on pressure altitude and density altitude later in this chapter in a section on aircraft performance indicators, but first we must cover temperature and moisture observations, which are necessary for those calculations.

REVIEW QUESTIONS

Q51. Ten millibars is equal to how many hectopascals?

Q52. What is meant by the term "removal correction"?

Q53. What would be the "r" factor for a shipboard barometer located 45 feet above the water line?

Q54. What is an altimeter setting used for?

Q55. How is the overall trend or characteristic of pressure tendency determined?

TEMPERATURE

LEARNING OBJECTIVES: Define temperature. Define and describe how to obtain dry-bulb temperature and wet-bulb temperature readings. Define and describe how to calculate dew-point temperature and frost-point temperature. Define sea-surface temperature and describe three methods used to obtain this reading.

Temperature is defined as the amount of sensible heat in a substance or as the measurement of molecular motion in a substance. Molecules in motion cause heat. As energy is added to a substance in the form of light or as infrared radiation (heat energy), the molecules absorb the energy, which increases molecular motion. This increase in molecular motion is measured as an increase in temperature. Higher temperature substances will also give off energy by radiation. Higher temperature substances can also transfer energy from faster moving molecules (warmer) to slower moving (cooler) molecules as the molecules collide. This process is known as conduction.

In surface aviation weather observations, observers take dry-bulb temperature and wet-bulb temperature readings by using sling psychrometers or electric psychrometers, or they obtain the readings from automatic weather station equipment. From these readings, the observer may calculate the dew-point temperature by using the CP-165/UM psychrometric computer, although automatic systems will calculate this important value. Related to the dew-point temperature is the frost-point temperature, which may need to be calculated. Another temperature required for shipboard surface aviation weather observations is the sea-surface temperature. Also, once each day, the observer must obtain a maximum and a minimum temperature reading.

DRY-BULB TEMPERATURE

The *dry-bulb temperature* (also called the ambient air temperature, or simply the air temperature) reflects the amount of heat present in the air. It is read directly from a ventilated thermometer on an electric psychrometer, sling psychrometer, rotor psychrometer, or from automatic measuring equipment. The temperature must be obtained to the nearest 1/10 degree and may be read in either Fahrenheit or Celsius degrees.

WET-BULB TEMPERATURE

The *wet-bulb temperature* is the lowest temperature an object may be cooled to by the process of evaporation. It is read directly from the wet-bulb thermometer on an electric psychrometer, sling psychrometer, or rotor psychrometer. Water evaporating from the moistened wick on the wet-bulb thermometer bulb cools the thermometer bulb and lowers the temperature reading. The cooling effect of the evaporation from the bulb is inversely proportional to the amount of water vapor present in the air: the more water vapor present, the less moisture will evaporate from the moistened wick, and the less cooling of the thermometer bulb will occur. From the dry- and wet-bulb readings, the dew-point temperature and humidity values may be calculated. The automatic weather observation systems do not provide a wet-bulb temperature, but automatically process equivalent measurements to compute dew-point temperature.

DEW-POINT TEMPERATURE

The *dew-point temperature* is the temperature a parcel of air must be cooled to in order to reach saturation. Cooling past the dew-point temperature normally results in condensation or precipitation. Changes in temperature do not alter an air-parcel's dew-point temperature; therefore, dew-point temperature is termed a conservative property. The extraction or addition of moisture, however, from or to an air parcel will respectively decrease or increase the dew-point temperature.

Dew-point temperature is calculated from the dry-bulb temperature and the wet-bulb depression by using the CP-165/UM psychrometric computer. The *wet-bulb depression* is the difference between the dry-bulb temperature and the wet-bulb temperature. Dew-point temperature is automatically calculated by the automatic weather systems.

Many calculations that you will be using call for a dew-point depression as a value. The *dew-point depression* is the difference between the air temperature and the dew-point temperature, expressed as a positive number. For example, if the air temperature is 78°F and the dew-point temperature is 67.5°F, the dew-point depression is 10.5°F.

FROST-POINT TEMPERATURE

The *frost-point temperature* is the temperature, below freezing, that a parcel of air must be cooled to in order to reach saturation. Cooling past the frost-point temperature normally results in sublimation of ice crystals from the air. The frost-point temperature is occasionally referred to as "the dew-point temperature with respect to ice." Calculations using the "low" temperature side of the CP-165/UM psychrometric computer refer to use of the "Ti" scale when the wet-bulb thermometer wick is frozen, and to the "DP" scale if the wet-bulb wick is not frozen. Both scales calculate a dew-point temperature with respect to liquid water, and not a frost-point temperature. The frost-point temperature may be approximated by the following formula:

$$T_F = \frac{9}{10} T_D$$

where T_F is the frost-point temperature, and T_D is the dew-point temperature.

As an observer, you may be asked to calculate frost-point temperatures, especially when working with a Skew T, Log P diagram. Although the frost-point temperature is not usually computed for a surface aviation weather observation, we have introduced it at this point because it is so closely related to the dew-point temperature. Relative humidity, and other humidity computations derived from temperature and dew-point temperature readings are covered later in this chapter.

SEA SURFACE TEMPERATURE

Another temperature reading in shipboard weather observations is the *sea surface temperature*. It is supposed to reflect the temperature of the upper few inches of the sea surface. On some ships with OA divisions, installed sensors automatically measure this value. There are three other acceptable methods for obtaining a sea-surface temperature reading: the bucket temperature method; by expendable bathythermograph; and by use of the seawater injection temperature. The sea-surface temperature reading must be accurate since it is a major input into many undersea warfare (USW) acoustic products.

Bucket Temperature

The *bucket temperature method* is by far the most accurate, yet is also the most work intensive. In this method, a sample of seawater is obtained by casting a lightweight bucket or coffee can with a strong line attached over the side of the ship and retrieving a water sample. This should be done as near to the bow of the ship as possible, since the passage of the ship through the water tends to mix surface water with water from the keel level of the ship. The "bucket" should also be cast ahead of where the observer is standing so that the bucket fills as it drifts by the observer. As the movement of the ship carries the bucket astern of the observer, the bucket should be retrieved. A standard thermometer is then inserted into the water sample, and the water is slowly stirred with the thermometer until the temperature reading stabilizes. The temperature is read to the nearest 1/10 degree Fahrenheit.

Bathythermograph Temperature

The next best method is to obtain a sea surface temperature from an *expendable bathythermograph* sounding. Procedures for conducting a bathythermograph sounding are covered in a later module. Bucket temperatures should be conducted occasionally to verify that the recorded bathythermograph surface temperature is accurate. *Sound* velocimeterreadings may also be used in lieu of a bathythermograph reading.

Seawater Injection Temperature

The least accurate method is the *seawater injection temperature* reading. Seawater injection temperatures are read in the engineering spaces and are usually readily available by shipboard phone from the "main engine room control" watch/operator. Seawater is constantly taken onboard for cooling the engines and for conversion to freshwater. The seawater injection ports are located well below the water line, sometimes as deep as 60 feet on aircraft carriers. Therefore, temperature readings at that point do not accurately reflect a sea surface temperature, but rather a near surface temperature reading.

In tropical waters, the difference between the surface temperature and the near-surface temperature is usually slight. But in certain regions of the mid- and high-latitudes, a strong surface thermocline may exist, which will cause a rapid decrease is temperature from the surface to the injection level. This may cause the difference between the actual surface temperature and the injection temperature to be very large. If injection temperatures are used, they should be routinely checked against bucket temperatures and bathythermograph temperatures, and adjusted if necessary.

REVIEW QUESTIONS

Q56. *Define wet-bulb temperature.*

Q57. *What is the normal result* of *air being cooled to below the dew-point temperature?*

Q58. *Given an air temperature* of *82.5°F and a dew-point temperature* of *70.0°F, calculate the dew-point depression.*

Q59. *What is meant by the term "frost-point temperature"?*

Q60. *List three methods for manually obtaining the sea surface temperature.*

WIND

LEARNING OBJECTIVES: Describe wind speed and wind direction. Define and identify how to determine true-wind direction, relative-wind direction, and magnetic-wind direction. Explain wind character and wind event. Define Foxtrot Corpin.

The atmosphere is essentially an ocean of air surrounding earth. Temperature is unevenly distributed over the earth's surface, varying with latitude and with the seasons. Therefore, all of earth's atmosphere is continuously in a state of fluid motion. Wind is the observed effect of horizontal transport of air masses over earth's surface. Surface winds are the movements of air within 50 feet of the ground. The term *winds* usually refers to both wind speed and direction. Different reporting codes require that observations be made over certain periods of time. Some conventions require a 2-minute observation period, while others require a lo-minute. These time periods are specified in NAVMETOCCOMINST 3141.2 and NAVMET-OCCOMINST 3144.1.

Winds are observed by using the equipment discussed in chapter 2. Automatic observation equipment will immediately report and record winds; other wind-measuring equipment can show a detailed graph of speed and direction over time. Winds are described by wind direction, wind speed, and wind character.

WIND DIRECTION

Wind direction is the average direction from which the wind is blowing during a specified period. Airflow from the north toward the south is referred to as a "North wind." Wind direction always shows minor fluctuations. These minor fluctuations are normally "averaged out" when determining a wind direction.

Several conventions are used to report wind direction. As a weather observer, you must be familiar with the relationship between these direction-reporting conventions.

Wind Direction Conventions

Wind directions are expressed in azimuth bearings or by the 8-point or 16-point compass. In addition, the wind direction may be a true, relative, or a magnetic wind direction. Wind directions are normally observed to the nearest 5° of azimuth, but reported (and forecast) to the nearest 10°.

POINTS OF THE COMPASS.—Points of the compass as represented in figure 1-30 are normally used only to express wind directions in general weather forecasts. They are not used in aviation observations or forecasts. The standard for expressing wind direction in most general public weather forecasts and military forecasts is the 8-point compass. It uses the cardinal points of the compass (north, east, south, and west) as well as the inter-cardinal points (northeast, southeast, southwest, and northwest). General marine area forecasts may also use intermediate compass points, such as North-Northeast, East-Northeast, and East-Southeast. When not specified as "relative" or "magnetic" directions, the points of the compass refer to "true" directions.

When wind direction is critical to the safe conduct of an operation or exercise, such as routine aviation weather operations, parachute operations, or the employment of weapons systems, both observed and forecast wind directions should be provided using azimuth bearings.

AZIMUTH BEARINGS.—In surface aviation weather observations, wind direction is always reported using a 360° azimuth circle with 000°/360° representing True North. Figure l-30 also shows an azimuth bearing circle. Note that the 0/360 azimuth bearing is aligned with *True North*, the North Pole. Directions are expressed in degrees of azimuth progressing clockwise through 090° representing due East, 180° representing due South, 270° representing due West, and 360° representing due North. In meteorology, an azimuth of 000° is used only when no wind is blowing, while 360° means the wind is from the North.

True Wind Direction

True North is represented on a globe as the North Pole. All directions relative to True North may be called "true bearings." Since the majority of azimuth bearings for wind directions and navigational bearings are required to be oriented to True North, a wind direction or navigational bearing lacking designation is assumed to be a "true" bearing. A *true wind direction* is a wind direction measured with respect to True North. The wind equipment installed at all shore weather stations should be oriented to True North. Therefore, wind direction and wind speed obtained from the equipment is considered to be a true wind direction and a true wind speed.

Relative Wind Direction

A relative bearing uses the current direction that an object (such as a ship or an aircraft) is facing as the 0/360° azimuth alignment. On a ship, a line taken through the centerline of the ship directly over the bow represents the relative bearing 0/360°. The relative azimuth bearings proceed clockwise with directly off the Starboard Beam representing 090°, dead astern representing 180°, directly off the Port Beam representing 270°, and back to the bow at 360°. Wind direction aboard ship is observed by relative bearing and is called a *relative wind direction.* The relative wind direction (and relative wind speed) may be manually converted to a true wind direction (and true wind speed) by using the CP-264/U true wind computer, a maneuvering board, or an aerological plotting board. Do not confuse relative wind with *apparent wind* (the relative wind speed with the wind direction reported using true bearing vice relative bearings). Apparent winds have no application in meteorological observations.

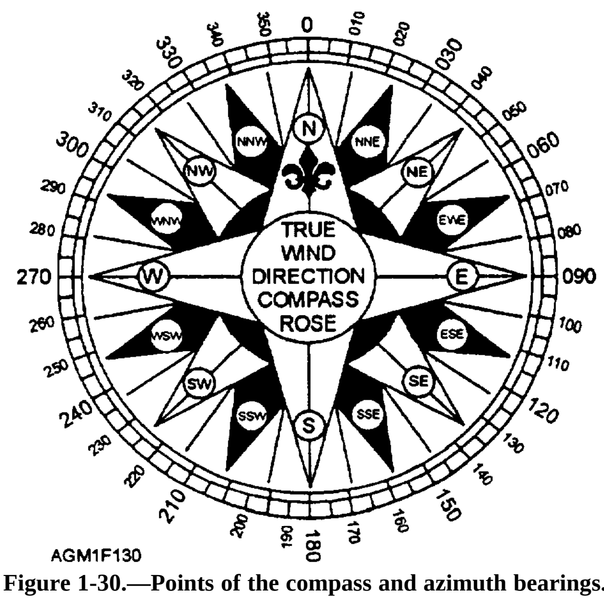

Figure 1-30.—Points of the compass and azimuth bearings.

Magnetic Wind Direction

A *magnetic wind direction* is a direction based on the 360° azimuth circle with the 0/360° azimuth radial aligned with magnetic north. Magnetic bearings are used by tactical weather observers in the field when determining wind directions by using a magnetic compass for reference. The magnetic wind directions thus obtained are converted to true wind directions by adding or subtracting the appropriate magnetic declination for the location. If, for instance, a charted magnetic declination is "7° west," this means that magnetic north is 7° west of actual or True North, and that 7° must be subtracted from the wind direction obtained to convert it to true wind direction. When a location has a declination east of true north, the correction must be added to the magnetic direction. As long as the tactical observer is stationary (not in a moving vehicle), no correction need be applied to the observed wind speed.

WIND SPEED

Wind Speed is the average rate of air motion, or the distance air moves in a specified unit of time. The *instantaneous wind speed* is the speed of the air at any moment. The instantaneous wind speed will usually show minor fluctuations over time. Fluctuations between the highest instantaneous speed and the lowest instantaneous speed are averaged to obtain mean wind speed. *Mean wind speed* is the arithmetic or graphical average wind speed during the period of observation, which is normally 2 minutes. For example, wind speeds on a recorder chart during a 2-minute observation period may constantly vary between 24 and 32 knots. The average, 28 knots, is the mean wind speed. Mean wind speed is the value observed and reported for "wind speed" in all meteorological observations.

All U.S. military weather observations use nautical miles per hour, or knots (kt) as the standard for measuring observed, reported, and forecast wind speeds. Unless stated otherwise, the U.S. National Weather Service commonly uses statute miles per hour (mph) for all winds speeds, since the public is most familiar with that measurement. Overseas, meters per second (m/s) is the most frequently used measurement. Navy and Marine Corps observers will frequently need to convert wind speeds from one measurement system to another. Wind speeds are normally observed and reported to the nearest whole knot. Occasionally, you may see reference to wind speeds on the Beaufort wind scale, such as "force 1 winds" or "winds 3 to 4, becoming 5 by night." *Force* is not always stated, but is assumed. The Beaufort wind scale is included and cross-referenced to standard wind speeds in the table in Appendix V.

Wind speeds aboard ship are affected by ship movement. If the ship is heading into the direction from which the wind is blowing, the observed wind speed across the deck will be greater than the actual wind speed. On the other hand, if the ship is traveling with the wind, the observed wind speed over the deck will be less than the actual wind speed. For this reason, the winds across the deck, as measured on an anemometer, are called *relative wind speeds;* the wind speed is relative to the motion of the ship. Relative wind speed is converted to *true wind speed,* which would be the actual wind speed if measured at a stationary location. You can convert relative wind speed to true wind speed by using the CP-264/U true wind computer (see chapter 2), or a maneuvering board may be used.

Many "descriptive" terms are used to identify wind speed. Some are *light breeze, fresh breeze, gentle breeze, moderate breeze,* or *fresh gale* and *storm.* These terms are part of an accepted scale of nautical wind speeds that may be directly related to wind speed measurements. These descriptive names are included in Appendix V. Others, such as *brisk* or *sultry,* although acceptable in literature, have only a vague relationship to measured wind speeds and should not be used. Only two descriptive terms may be used in military surface weather observations for wind speeds. They are *light,* abbreviated *LGT,* meaning the wind speed is 10 knots or less, and *calm,* meaning there is no detectable motion of the air.

WIND CHARACTER

In addition to wind speed and wind direction, most observations require a determination of wind character. *Wind character* is a description of how the wind (speed or direction) changes during the specified period. Wind speed gusts, the peak wind gust, wind speed squalls, and variable wind direction are all included in wind character, and should be noted during an observation.

Gust

A wind *gust* is a rapid fluctuation in wind speed with a variation between peaks and lulls of 10 knots or more. Gusts are normally observed in the 10-minute period prior to the actual time of observation. Gusts increase the difficulty of controlling aircraft during takeoff and landing. The *gust spread* (the difference in knots between the normal lulls and peaks), if large enough, may cause problems for rotary wing aircraft by initiating rotor chop. Rotor chop is a difficult to control, sometimes hazardous, up and down oscillation of the rotor blades. The *peak wind speed* or *peak gust* is the highest instantaneous wind speed or gust speed greater than 25 knots observed since the last METAR observation.

Variable Winds

Variable winds occur when the wind direction fluctuates by 60° or more. While this condition occurs most frequently when the winds are very light, wind direction fluctuations are most significant when the wind speeds are higher (greater than 6 knots). For observation purposes, the wind direction may be considered variable anytime the observed 2-minute mean wind speed is 6 knots or less.

WIND EVENTS

Certain wind phenomena are included in an observation even though the events did not occur during the 2- or 10-minute period during which the winds were being observed. These phenomena or events may be included in the observation if they occurred within the past hour and were not reported in a previous observation. The events include squalls and wind shifts.

Squalls

A *squall* is a sudden large increase in wind speed (usually accompanied by a change in wind direction) that lasts several minutes and then suddenly dies. For observation purposes, the wind speed must increase by 16 knots or more and the sustained wind speed after the increase must be 22 knots or more for at least 1 minute. Squalls are usually caused by large convective cells, like those that produce strong rain showers and thunderstorms. Squalls may also be produced by dry frontal passages; the presence of precipitation is not a requirement. At sea, strong rain showers at a distance away from the ship are called "squalls" because squall winds are usually present. When lines of thunderstorms form on or move out ahead of a cold front, the line may be called a "squall line" because of the squall winds associated with the thunderstorms.

Wind Shifts

A *wind shift* is any change in wind direction by 45° or more during a 15-minute time period. The change in direction may or may not be accompanied by a change in wind speed. However, wind shifts are only recorded when the mean wind speed is 10 knots or greater during the shift. A wind shift may be very sudden, occurring within a minute or so, or it may occur gradually over the 15-minute period. The most common cause of wind shifts is frontal passage, especially a cold-frontal passage. The onset of a sea breeze may cause a wind shift, as may other locally produced wind conditions.

FOXTROT CORPIN

Foxtrot Corpin is the term used to identify the best course and speed a ship should "come to" to bring the relative wind into the proper window for the launch and recovery of aircraft. For departures and recoveries aboard different classes of ships, the most desirable relative wind speed, acceptable minimum and maximum wind speeds, the most desirable relative wind direction, and the acceptable wind direction variations are specified in the *NATOPS Flight Manuals* for each type of aircraft.

Foxtrot Corpin is routinely provided by Aerographer's Mates aboard aircraft carriers and amphibious assault ships and is computed by using the CP-264/U true wind computer. Detailed instructions for the procedure are printed on the reverse side of the CP-264/U. The procedure uses the true wind and the desired wind to find required ship's course and speed.

REVIEW QUESTIONS

Q61. Explain the difference between True North and Magnetic North.

Q62. Winds blowing directly off the starboard beam are coming from what relative direction?

Q63. How can relative winds be manually converted to true winds?

Q64. How is the mean wind speed determined?

Q65. How would the observed wind speed on a ship be affected by winds blowing from dead astern?

Q66. Define the term "gust."

Q67. Define the term "squall."

SEA AND SWELL WAVES

LEARNING OBJECTIVES: Explain the importance of sea conditions to naval operations. Define duration limited seas and fetch limited seas. Define wave height, wave length, and wave period, and wave direction. Define and distinguish the difference between sea waves and swell waves. Define Romeo Corpin.

Sea conditions are critical to carrier flight operations, replenishment operations, undersea warfare operations, amphibious operations, and search and rescue missions. Your observations of sea conditions are vitally important. They must be accurate so that forecaster and operations personnel may predict the success of planned operations. The majority of waves are disturbances on the surface of the water produced by blowing winds. Although there is some net displacement of water in waves, the majority of the movement of water in a wave is in a circular motion beneath the surface. Waves move across the surface of the water by transferring energy—not matter. Waves move in a sine wave pattern, as shown in figure 1-31.

WAVE PARAMETERS

The success of any operation conducted in the ocean environment may depend on the height of the seas, the direction of the seas, and the wave period. Waves, in general, are described by wave height, wave length, and wave period. Wave direction is another important aspect used to describe waves.

Wave Height

In oceanography, *wave height* (fig. l-31) is the vertical distance, usually measured in feet, from the *crest* of a wave (the highest portion of a wave) to the *trough* of the wave (the lowest portion of the wave). This differs from the "wave height" or "amplitude" normally used in physics, in which the distance is measured from the "at rest" or midline position to the crests and troughs. When waves are generated by the force of wind acting on the water, the wind speed determines the maximum height of the wave. For a given wind speed, many different wave lengths (frequencies) are produced, and for each wave length (frequency), many different wave heights are developed. Although the general relationship that higher waves tend to have longer wave lengths (lower frequencies) is true, there is no specific relationship between wave height and wave length.

The primary factor that determines the maximum wave height is the wind speed. But the *duration* of the wind (length of time the wind has been blowing at a certain wind speed) and the *fetch,* (distance over the water the winds have been blowing) also limit the maximum wave height. When the highest theoretical wave height based on the wind speed cannot be attained because the winds have not blown for a sufficient period of time, the sea heights are said to be *duration limited.* When the sea heights cannot be attained because the straight line area the winds have been blowing over the water is too short, the sea heights are said to be *fetch limited.* The tables in Appendix V provide a breakdown of wind speeds in relation to wave heights and a wind and sea scale for a fully arisen sea.

The table in Appendix V also refers to the 10 states-of-the-sea, or sea-states. Although not used extensively, sea-states may be mentioned in literature or messages. *Sea-states* refers to general descriptions of wave heights and the appearance of the water surface. They range from "calm" and "sea like a mirror," as in sea-state 0, to "exceptionally high waves" with the "air filled with foam and spray" as in sea-state 9.

Accurate observations of wave height are the most difficult determination in an observation, especially from the catwalk on an aircraft carrier. Typically, observers on large ships, such as an aircraft carrier, significantly underestimate the wave height, while observers on smaller ships and in small boats provide

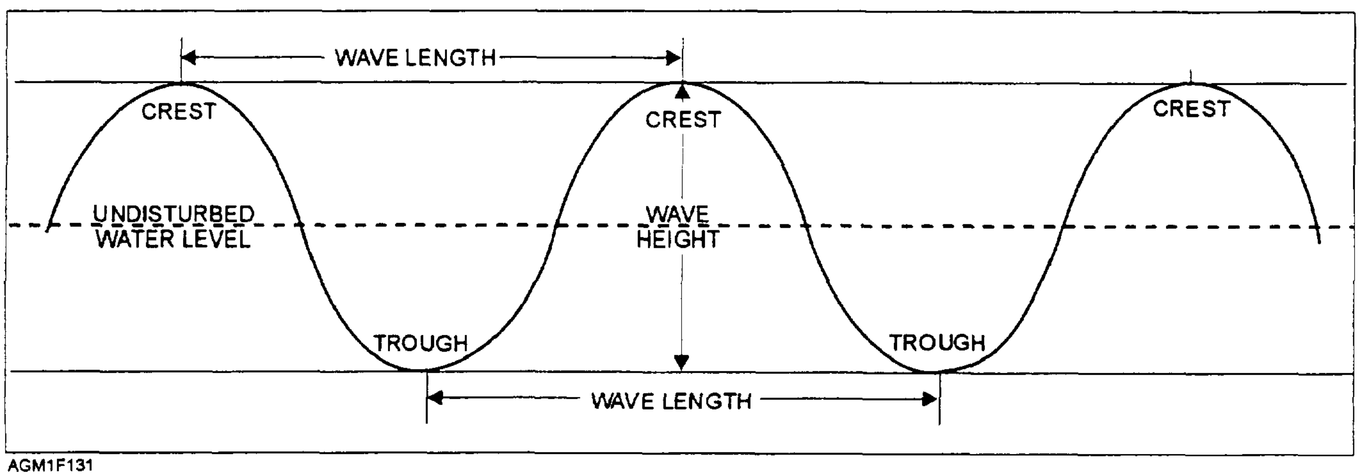

Figure 1-31.—Sine wave pattern and associated parameters in ocean waves.

the most accurate wave height estimations. This is understandable since an observer on a carrier catwalk is some 60 feet above the water line, and the waves look small from that height. Estimation may be improved by observing wave height from the hangar deck, which is only some 30 feet above the water. Until the observer becomes very experienced in observing wave heights, reference objects should be used to judge the wave height.

Good reference objects are ships-in-company or small boats operating alongside. Waves may be compared to the heights of the freeboard along the sides of the ships, or to the size of the small boats. "Load line" markings in feet may be visible on the sides of ships and will assist in wave height determination. Be careful not to observe the waves near the bow of a ship, since the bow-wave is caused by the ship and is not a true representation of the actual wave heights.

The best reference object is something of known size. Some shipboard weather offices keep square 1-, 2-, or 3-foot pieces of cardboard on hand to throw over the side of the ship and use as a reference. Other ships use 1-foot-square pieces of scrap wood as a reference. (Cardboard is preferable, since it will soon become soggy, breakdown, and sink in the water, and it is biodegradable. It is also readily available.) Using a block of wood or cardboard as a reference is known as the *chip* or *block method.*

Wave Length

Wave length is the horizontal distance from one wave crest to the next wave crest, or the distance from one wave trough to the next wave trough. Although difficult to measure at sea, this parameter may be measured on aerial photographs and is directly related to wave period by the approximation $L = 5.12T^2$, where L is the wavelength in feet and T is the wave period in seconds. Wave lengths are not directly observed or reported by observers.

Wave Period

Wave period is the time, usually measured in seconds, that it takes for a complete wave cycle (crest to crest or trough to trough) to pass a given fixed point. Wave period is dependent upon the speed of movement of the wave across the surface. The speed of movement varies with wave length, with shorter wave-length waves moving slower and longer wave-length waves moving faster. This relationship is approximated by $C = 1.34\sqrt{L}$, where C is the wave speed (knots) and L is the wave length. Many calculations dealing with waves use the wave frequency instead of the wave period as a basis for the argument. The wave *frequency* is the number of wave cycles passing a fixed point in 1 second, and it is inversely proportional to wave period. Conversions between wave frequency (f) and wave period(T) are made by the formula $f = 1/T$ or $T = 1/f$.

Wave Direction

Wave direction is the direction, in true degrees of azimuth, that the majority of the waves in a group are coming from. Wave direction is best determined during an observation by sighting along the wave crests and troughs and either adding 90° to or subtracting it from the direction obtained, as shown in figure 1-32. Use the gyroscope repeater on one of the pelorus columns (chapter 2, fig. 2-29) to sight along the wave crests or troughs. Add or subtract 90° to/from the true bearing thus obtained to determine the wave direction. The observer may also sight directly into the oncoming waves, perpendicular to the crests and troughs, to obtain wave direction.

SEA WAVES

Sea waves, often referred to as "seas," are waves generated by the wind in the local area. Light winds

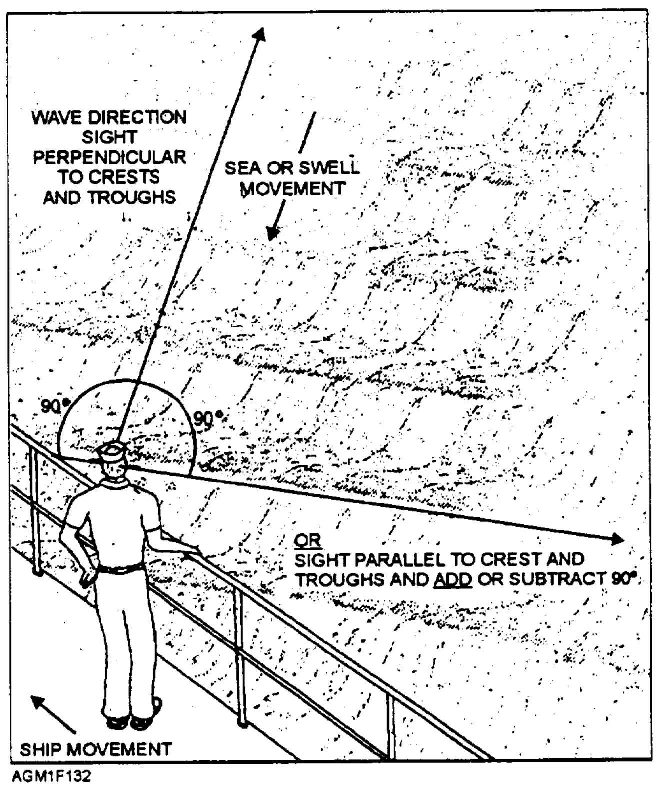

Figure 1-32.—Method for obtaining wave direction.

usually produce seas with small wave heights, small wave lengths, and short periods; higher winds usually produce waves with higher heights, longer wave lengths, and longer periods. When the winds over the water produce sea waves, the wave crests are generally aligned perpendicular to the direction the wind is blowing. The continuing force of the wind on the waves distorts the ideal sine wave pattern, forming sharper crests (fig. 1-33). The waves move in the direction the wind is blowing, with wave crests and troughs perpendicular to the wind direction.

In a given sea condition, many different size waves are present. Observers determine *significant wave height*, or the average wave height of the highest 1/3 of all the waves present. Ideally, the heights of 50 to 100 waves should be recorded on a piece of paper, then the highest 1/3 of the recorded heights should be averaged to obtain significant wave height for the seas. In practice, taking the average height of the "most well defined" waves approximates the significant wave height. Attempt to observe 50 or so waves as a minimum, and then average the height of the "best" 16 or 17 waves.

The average significant wave period in an area of sea waves gives analysts and forecasters a better idea of the total wave energy present in the area than does the observation of the significant wave height. Observations of the average significant period should be made by timing the passage of "well defined" wave crests past a fixed point, such as a buoy, clump of seaweed, wood block, or square piece of cardboard mentioned earlier, and then dividing to find the average. The observer should attempt to time the passage of the same "significant" wave crests that were used in the determination of average significant wave height. If, for example, you timed the passage of 17 "well defined" waves out of 50 waves of various size passing the cardboard square (before you lost sight of the square) in 120 seconds, the average wave period is 120/17, or 7 seconds. The important factor in determining both the average height and the average period for sea waves is that only the highest 1/3 of the waves, the significant waves, are evaluated.

A direction is always determined for sea waves, and the direction found should be in general agreement with the wind direction. If the sea wave direction does not agree within plus/minus 20° of the wind direction, recheck both sea and wind direction. The sea direction is usually not recorded or reported, since it is assumed that the sea direction is nearly the same as the recorded wind direction.

SWELL WAVES

Swell waves are seas that have moved out and away from the area in which they were formed. Because of their different wave lengths and wave speeds, waves move outward from the windy areas where they formed, and separate into groups of waves with distinct wave periods. Since the winds are no longer pushing on the waves, they take on a more typical sine wave pattern with generally equally rounded crests and troughs, and thus are smooth and regular in appearance.

Typically, when only one group of swell waves is present, the wave heights and the wave periods are fairly uniform. Determinations for the average swell wave period, the average swell wave height, and the wave direction may be easily made. When determining

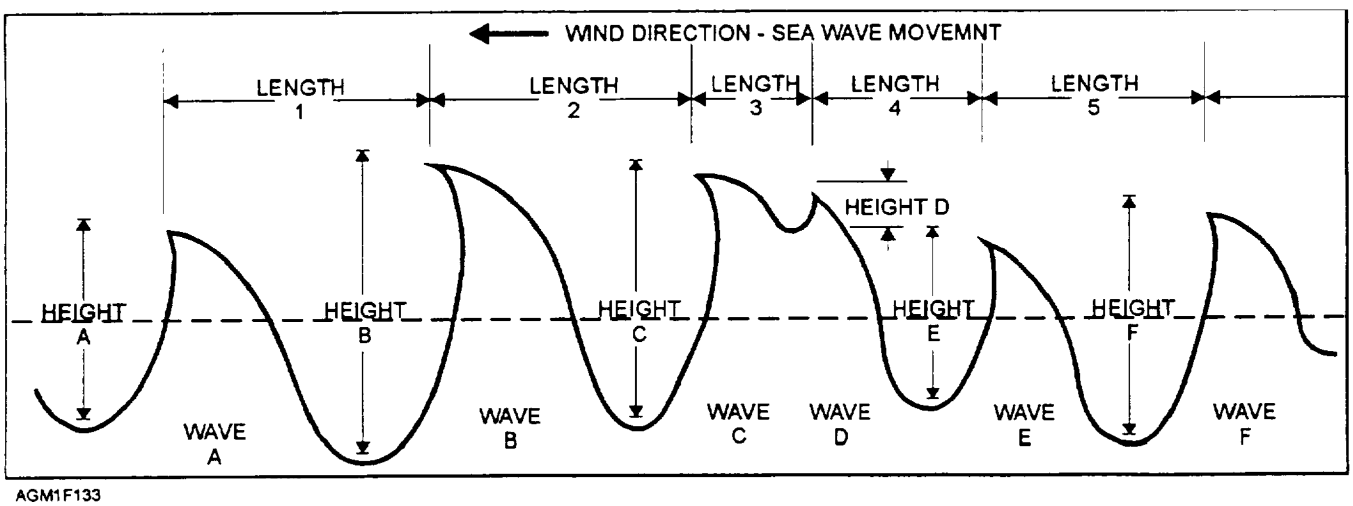

Figure 1-33.—Typical sea wave pattern. Note the sharper crests and the irregular wave pattern caused by the superposition of many different wave length/wave height patterns.

the average swell wave height, use the height of all of the swell waves, not just the highest 1/3, as used for sea waves. Similarly, when determining average period, count and time all of the rounded swell wave crests passing the fixed reference pointed. Make swell wave observations from the side of the ship the waves are approaching from to see the wave pattern better. The swell wave direction should be determined from a relatively high position on the ship so that a larger area of the sea may be observed.

Frequently more than one group of swell waves may be observed, each coming from a different direction. When this happens, you should attempt to determine average height, average period, and direction for each swell wave group. Swell wave groups should differ in direction from each other or from the sea waves by 30° or more to be considered and reported in an observation.

Further information on sea and swell wave observations is contained in NAVMETOCCOMINST 3144.1, as well as H.O. Pub 603, *Practical Methods for Observing and Forecasting Ocean Waves.*

ROMEO CORPIN

Shipboard Aerographer's Mates are occasionally tasked to recommend Romeo Corpin for underway replenishment (UNREP) operations, including connected replenishment (CONREP) and vertical replenishment (VERTREP). *Romeo Corpin* is the best course and speed a ship should "come to" to minimize the effects of the seas and swell on the ship. Wind is also an important consideration. The most desirable course gives the ship the most stable passage to minimize roll, pitch, and yaw of the ship, while limiting the apparent winds across the deck to a safe working level for personnel. During VERTREP operations, Romeo Corpin may be limited by the relative wind requirements for the helicopters involved. General guidance for determination of Romeo Corpin is found in *Underway Replenishment,* NWP 4-01.4. Much of the necessary guidance for the best replenishment course depends on how each individual ship type handles in different sea conditions. This information may be obtained from a qualified Underway Officer of the Deck. All requests for Romeo Corpin should be referred to the Forecaster.

REVIEW QUESTIONS

Q68. Define wave height.

Q69. What factors will determine the maximum height of sea waves for any location?

Q70. What would be the average wave height with a sea state of 5?

Q71. Define wave period.

Q72. How is wave direction determined?

Q73. What is meant by the term "significant wave height"?

Q74. How do swell waves differ from sea waves?

Q7.5. How is swell wave height determined?

ICE ACCRETION

LEARNING OBJECTIVES: Define ice accretion. Describe the characteristics of ice accretion. List elements to be included in the observation of ice accretion.

Ice observations are conducted as part of general shipboard weather observations. *Ice accretion* is the accumulation of clear ice (glaze) or rime ice on the outside structures of a ship. Ice may form on a ship when the air temperature is below freezing and hydrometeors are present. Glaze commonly forms when the air temperature is between 32°F and 25°F (0°C and -4°C) with dense fog, freezing rain or drizzle, or blowing spray. Below 25°F the probability of freezing precipitation drops sharply. As the temperature approaches 14°F, (-10°C), fog and blowing spray form rime ice rather than clear ice, because the freezing occurs too fast for the trapped air bubbles to escape. Ice tends to accumulate first on wires, railings, masts and exposed fittings, and then on flat surfaces receiving little heating from the interior of the ship. Ice accumulates last on decks and bulkheads heated from within the ship. Ice accretion is dangerous not only to personnel who must walk across or work on the weather decks, but to the ship as well. Ice accumulations may break wires and antennas. If the accumulation is heavy enough, the added weight on the superstructure may cause the ship to roll excessively or capsize.

Observations of ice accretion include a determination of the source of the moisture, such as fog, blowing spray, or freezing precipitation, as well as an average measurement of the thickness of the accumulated ice, in centimeters. The observation also requires a determination of the rate of accumulation or melt-off.

REVIEW QUESTIONS

Q76. At approximately what temperature (Fahrenheit) would you expect rime ice to form on a ship, assuming blowing spray is present?

Q77. What elements are included in an ice accretion observation?

ICE IN THE SEA

LEARNING OBJECTIVES: Explain the importance of sea ice to naval operations. Describe the various sea ice classifications, sea ice sizes, and topography of sea ice sheets. Discuss movement of sea ice and ice of land origin. Explain the judgments to be made when observing ice in the sea.

Roughly three percent of the world's water areas are covered in ice. Although small in area, the ice-covered areas of the sea and oceans are important to naval operations because of their proximity to possible hostile forces. Many submarines routinely operate beneath the ice, and surface ships occasionally operate in ice-covered seas or areas frequented by icebergs. The Naval Ice Center in Suitland, Maryland, keeps the Fleet advised of the development, movement, and equatorward limit of the ice edge, as well as of the location and movement of icebergs. Although they make extensive use of satellite imagery to detect and track ice, the ice observations from ships operating near the ice provide valuable input to this critical tracking and forecasting effort. Observations of ice seen floating in the sea are completed as part of each surface weather observation.

There are two main types of ice found floating in the sea: sea ice and ice of land origin.

SEA ICE

Sea ice is ice that forms in the sea. It is, for the most part, frozen seawater. Sea ice accounts for approximately 95% of the ice coverage in the oceans.

For seawater to freeze, the temperatures must be colder for a longer period of time. This is due to the salinity of the water and because of the density changes in the water caused by the salinity. We know that pure water freezes at 0°C (32°F) but the freezing point of seawater varies, depending on the salinity (fig. 1-34). Seawater averages 35‰ or 35 parts per thousand by weight salinity. With this salinity, water begins to freeze at -1.9°C (28°F). Freshwater reaches maximum density at 4°C (39°F). In effect, as freshwater ponds and lakes cool, and the surface waters reach 4°C the water sinks and warmer subsurface water rises to replace it. This slows the process of cooling the surface of the pond below 4°C until the entire body of water is cooled to 4°C. After this point, surface waters cooled to less than 4°C are slightly less dense than the water below the surface, and cooling to the freezing point is rapid. Seawater on the other hand, reaches maximum density at the freezing point. When surface seawater is cooled to the freezing point, but before ice can form, the water sinks and is replaced from below by slightly warmer water. The overturn process continues for a long period of time, even in continued subfreezing air temperatures, until a large column of water can be cooled. Overall, the lower freezing point and greater overturn required makes the freezing process of seawater very slow. The freezing of seawater is further retarded by the mixing action of winds (waves), currents, and tides. Once ice forms, it floats. Ice, even saltwater ice, expands as it freezes, so it is less dense than water at the same temperature.

The formation of sea ice usually begins with the onset of autumn, and the first ice usually appears in the mouths of rivers that empty into shallow seas, such as that off northem Siberia. During the increasingly longer and colder nights of autumn, ice forms along the shorelines (fast ice) and becomes a semipermanent

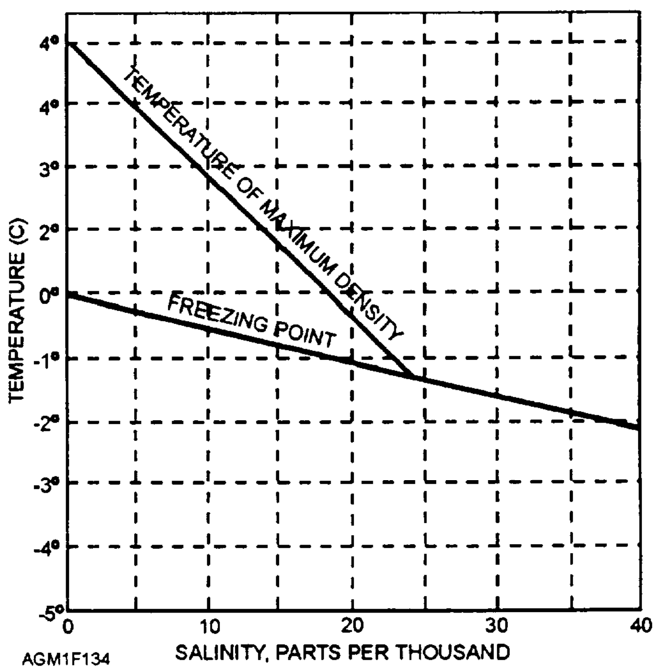

Figure 1-34.—Freezing point and temperature of maximum density versus water salinity.

feature that widens and spreads. When islands are close together, as in the Siberian Sea, fast ice blankets the sea surface, and bridges the waters between all land areas.

On the average in the Northern Hemisphere, sea ice is at a minimum in September, and at a maximum in March. In the Southern Hemisphere, these times are nearly opposite; minimum in March and maximum in September.

The first indication of ice formation is the presence of fine ice crystals on the surface of the water, producing a "slushy" water appearance.

Sea Ice Classification

As sea ice forms and grows, it is generally categorized into one of four groups: newly formed ice, young ice, first-year ice, and old ice.

NEWLY FORMED ICE.—In the open sea, the first sign that the sea surface is freezing is an oily appearance of the water. This is caused by the formation of *spicules* (minute ice needles) and *frazil* crystals (thin plates of ice). As formation continues, the surface attains a thick, soupy consistency termed *grease ice.* Eventually, *slush* and/or *shuga* (spongy white ice clumps) will begin to appear. Next, depending on the wind, waves, and salinity, an elastic or brittle crust forms. The elastic crust *(nilas)* has a matte appearance, while the brittle crust *(ice rind)* is shiny. As the crust thickens, the wind and sea cause the ice to break up into rounded masses known as *pancake ice.* With continued freezing, the pancake ice forms into a continuous sheet.

YOUNG ICE.—This ice sheet forms in 1 year or less, and its thickness ranges from 10 to 30 centimeters (4 to 12 inches). It is further classified as gray ice and gray-white ice.

FIRST-YEAR ICE.—This ice is a more or less unbroken sheet of ice of not more than one winter's growth that starts as young ice. Its thickness is from 30 centimeters to 2 meters (1 foot to 6 1/2 feet). First-year ice may be subdivided into thin first-year ice, medium first-year ice, and thick first-year ice. The latter is more than 4 feet thick.

OLD ICE.—Old ice is extremely heavy sea ice that has survived at least one summer's melt. It occurs primarily in the Arctic and Antarctic polar packs as a mass of converging and dividing ice floes of various ages, sizes and shapes. Old ice may be subdivided into second-year ice and multi-year ice.

Sizes of Sea Ice

Sea ice generally forms in vast sheets frozen solidly to the shores of islands and land masses; such areas of ice are called *fast ice.* The effects of winds and currents may break up fast ice sheets into smaller free-floating pieces of sea ice. Sea ice is categorized into seven different sizes, ranging from "small ice cakes" to "giant ice floes." Refer to figure 1-35 for relative sizes and a comparison to more common features. When the majority of the water area is covered in ice floes, the ice is generally called *pack ice.* A similar term, *the ice puck,* refers to any very large area that is predominately covered in ice.

In the Arctic and Antarctic, some areas of fast ice persist for many years. The frozen layers of seawater collect layers of snow that build up and are compressed into ice. These areas may develop ice sheets many hundreds of feet in thickness. Vast areas of seawater may be covered by these permanent areas of ice, which is called *shelf ice* or an ice shelf. As pieces of shelf ice along the edges of the ice sheet break free, they become icebergs.

Open Water Around Sea Ice

The same forces that separate ice floes from the fast-ice sheet also create various openings of unfrozen water between the ice floes. Naval operations in and around fields of sea ice can be hazardous. The movement of massive floes of ice can cut off ships from open water; worse yet, the ice may close in around a ship, leaving it stranded in a sea of ice. Therefore, changes in the size of open water areas in ice-covered seas becomes very important.

Many water features are associated with sea ice. Some of the more common features are as follows:

- *Fracture*—Any break or crack through the ice sheet
- *Lead*—A long, narrow break or passage through the sea ice sheet or between floes; a navigable fracture. A lead may be open or refrozen
- *Puddle*—A depression in sea ice usually filled with melted water caused by warm weather
- *Thaw hole*—A hole in the ice that is caused by the melting associated with warm weather
- *Polynya*—Any sizable area of seawater enclosed by sea ice. Put simply, a large hole in the ice

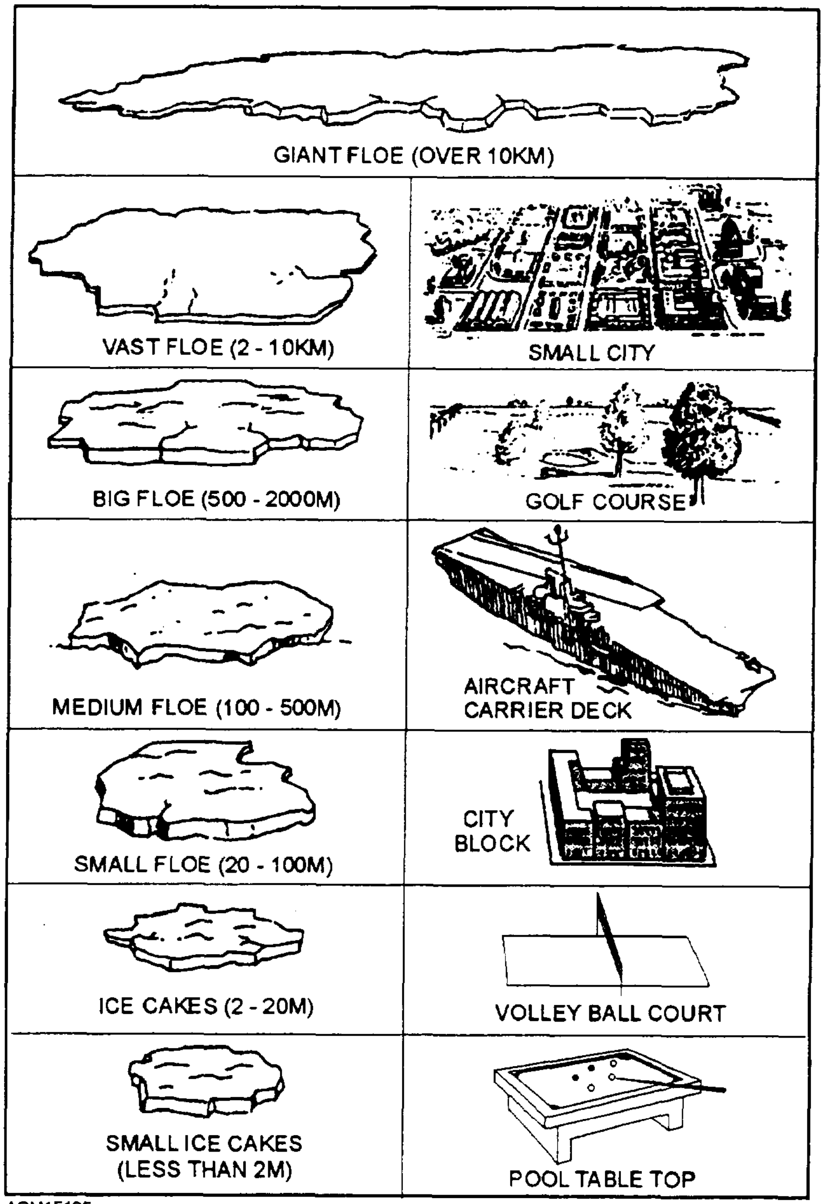

Figure 1-35.—Sizes of sea ice.

Topography of Sea Ice Sheets

In addition to separating pieces of sea ice from the fast ice by pulling it apart, the winds and currents may also push on fast-ice sheets, causing stress budges or stress ruptures in the surface with portions of the sheet overriding other sections. Many of these stress-induced features are identified by specific terms that describe the topography, or configuration of the ice surface. These terms are related to the degree of ice-surface roughness. Figure 1-36 illustrates the types of topography.

RAFTED ICE.—This type of topography occurs when ice cakes override one another. Rafting occurs when wind forces ice cracks or ice floes together. It is associated with young and first-year ice. When the rafting process is occurring, there is great compression within the ice sheet. Ships should avoid operations in any opening in the ice in an area where rafting is occurring, because it indicates the ice is closing in rapidly.

RIDGED ICE.—Ridged ice is much rougher than rafted ice and occurs with first-year ice. Wind and weather eventually smooth the surface of the ridges.

HUMMOCKED ICE.—Hummocking occurs with old ice. It is defined as ice piled haphazardly into mounds or hillocks. At the time of its formation, hummocked ice is similar to rafted ice; the major difference is that hummocked ice, because of its thickness, requires a greater degree of pressure and heaping.

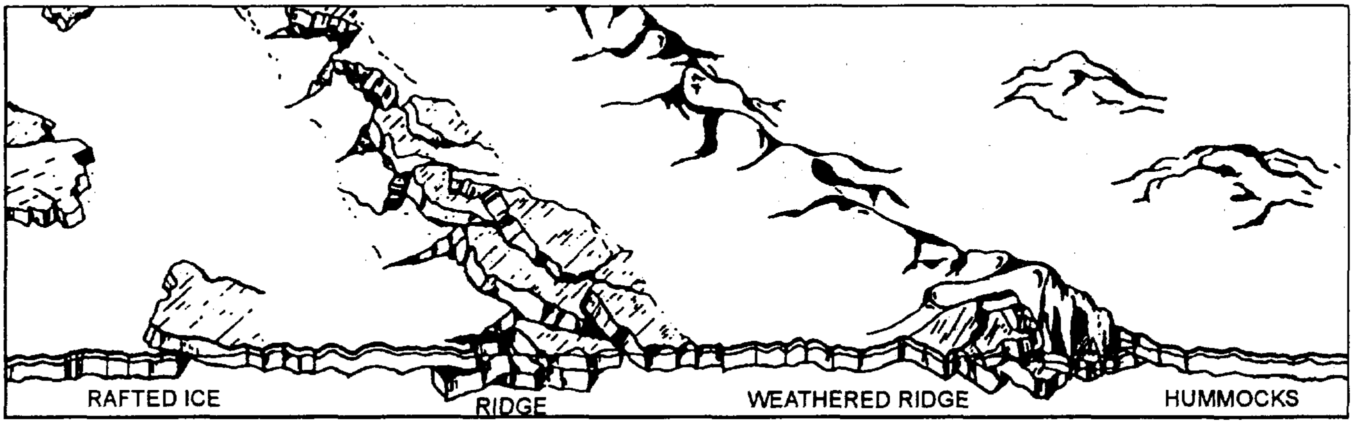

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Figure 1-36.—Various types of ice topography caused by pressure.

Movement of Sea Ice

As floes break free of the fast-ice sheet, they move under the effects of the winds and currents. Any movement of ice floes is called "drift." Drift refers to sea ice, as well as broken off portions (outer edges) of fast ice that moves along with wind, tides, and currents. Drift may, therefore, be more specifically defined by direction and speed of movement.

Pack ice usually drifts to the right of the true wind in the Northern Hemisphere (left in the Southern Hemisphere). Observations show that the actual drift is about 30° from the wind direction, or very nearly parallel to the isobars on a weather map. The drift more closely follows the wind in winter than in summer. In summer, the tides play a bigger role in the movement of the ice.

A close estimate of the speed of drifting pack ice is possible by using wind speed. On the average, the drift of ice in the Northern Hemisphere ranges from 1.4% of the wind speed in April to 2.4% of the wind speed in September. Although wind is the primary driving force, the presence or absence of open water in the direction of the drift greatly influences the speed of drift. Ice-free water in the direction of the drift, no matter how distant, permits the pack ice to drift freely in that direction. Ice-clogged water, on the other hand, slows the forward movement of ice.

ICE OF LAND ORIGIN

Ice of land origin is ice that forms on land, usually as glaciers, and moves to the sea. Composed by large accumulations of compacted (freshwater) snow on land areas, the weight of the accumulated snow/ice forces the ice sheets to move as glaciers. If a glacier is located along a coastline and reaches the sea, the leading edge of the glacier may break off (calve) and fall into the sea. This ice then drifts to sea as an *iceberg.*

Since 86% of the world's glaciers occur in Antarctica, most icebergs originate around that continent. Most of the remainder of the world's glaciers are located in Greenland. Greenland is the main source of icebergs in the Northern Hemisphere (about 90%). Nearly 70% of Greenland's icebergs originate along the western coast near 68°N.

ICEBERG CLASSIFICATION

Icebergs are classified by shape and by size. As classified by shape, icebergs are either pinnacled or tabular. *Pinnacled bergs* are generally cone-shaped, but may be very irregular. *Tabular bergs* are generally flat-topped and straight-sided. See figure 1-37.

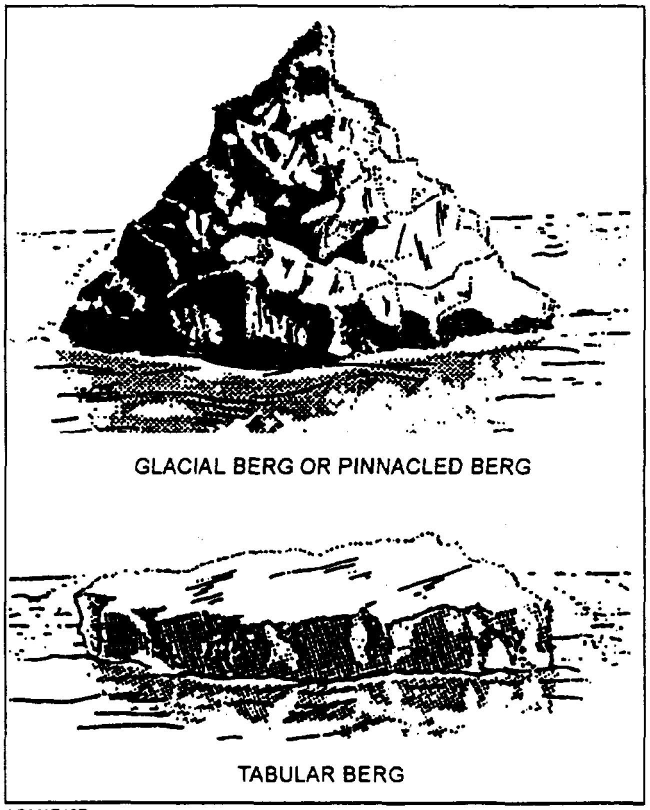

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Figure 1-37.—Types of icebergs.

The structure of an iceberg, and to some extent the appearance, depends upon the ice that produced the berg. Pinnacled bergs come from glaciers that plow across uneven ground on their way to tidewater, but may also develop as fragments that break off of shelf ice. Tabular bergs are produced as portions of sheet ice separate and float free, but may also be produced as large portions of shelf ice break free. Pinnacled bergs are more common in the Northern Hemisphere, while tabular bergs are more common in the Southern Hemisphere.

Icebergs are simply called "icebergs" when they are large or massive. Smaller pieces of ice are called "bergy bits" and "growlers." Like icebergs, bergy bits and growlers originate from glaciers or shelf ice. They may also form as larger icebergs disintegrate. A *bergy bit* is a medium-size fragment of glacial ice, or about the size of a small cottage. A growler is a small fragment of ice about the size of a truck. It is usually of glacial origin, and generally greenish.

Origin Characteristics

Icebergs originating in Greenland average 70 meters in height and 280 to 450 meters in length when first formed. The largest ones may exceed 400 feet in height and several miles in length. The tabular bergs of Antarctica average 30 to 40 meters in height, but their horizontal dimensions greatly surpass the bergs of the Northern Hemisphere. For example, one iceberg observed near Scott Island in 1956 measured 60 miles by 208 miles.

The portion of an iceberg that is visible above the water is dependent upon the type of the berg and the density differences between the seawater and the ice. The type of berg (pinnacled or tabular) determines the height of the ice above the water. In the case of the tabular berg, the depth below the surface is about 7 times the height above the water line. In the case of the pinnacled berg, the depth below the surface averages about 5 times that above the water line.

With regard to density, seawater with a temperature of -1°C and a salinity of 35% produces a density condition that allows nearly 90 percent of the ice to be submerged.

Pinnacled icebergs often have rams (protrusions of ice beneath the surface). These rams can be a great hazard to vessels that might pass close by bergs of this type. The *S.S. Titanic* sank in the North Atlantic with a great loss of life after striking this type of iceberg.

Movement of Icebergs

While the general direction of the drift of icebergs over a long period of time is known, it may not be possible to predict the drift of an individual berg at a given place and time. Bergs lying close together have been observed to move in different directions. The reason for this is that icebergs move under the influence of the prevailing current at the iceberg's submerged depth. The subsurface currents often opposes the existing winds and near-surface currents.

OBSERVING ICE IN THE SEA

When making an observation of ice in the sea, either sea ice or icebergs, you must determine the type of ice present. If the ice is sea ice, you must determine the size of the area covered by ice, the arrangement of ice, and the stage of development. If icebergs are present, you must determine the number of bergs present. If the ship is approaching an ice field, the direction of the ice edge relative to the ship's position must also be determined. Finally, a determination of the ship's ability to operate in the ice and the trend of any changes in the ice conditions must be made. Although these determinations sound complex, they are relatively easy. NAVMETOCCOMINST 3144.1 provides a detailed list of the determinations that must be made. Additional information on ice is available in the *Ice Observation Handbook*, published by the Naval Ice Center, Suitland.

In this section, we have discussed the various procedures used to observe the different elements in surface weather observations and surface aviation weather observations. We have also introduced many technical terms used to discuss and accurately describe the weather elements. Later, we will cover the observation recording methods and the specific code forms used to report surface weather observations. However, before we discuss that information, we must discuss some calculations that the observer is routinely asked to determine from data measured during the weather observation.

REVIEW QUESTIONS

Q78. Why does it take seawater longer to freeze than freshwater?

Q79. When does sea ice reach a maximum in the Northern Hemisphere?

Q50. What is meant by the term "fast ice"?

Q51. Why should ships avoid operating in ice areas where rafting is occurring?

Q82. How does pack ice normally drift in the Northern Hemisphere during winter?

Q83. Where do most of the world's icebergs originate?

Q84. What is the most important influence us to the movement of *icebergs?*

Q85. What publication provides detailed instructions for *reporting ice in the sea?*

COMPUTATION OF PHYSIOLOGICAL INDICATORS FROM OBSERVED DATA

LEARNING OBJECTIVES: Define heat stress. Identify the signs of heat exhaustion and heat stroke. Define relative humidity (RH) and identify how relative humidity and the General Heat Stress Index (GHSI) relate to heat stress. Describe the procedure used to compute GHSI. Identify the difference between the GHSI computed by weather personnel and the Wet-bulb Globe Temperature (WBGT) index used by some military personnel. Explain the effects of cold on the body. Define wind chill temperature and describe the procedure used to determine wind chill temperature. Explain seawater immersion survivability.

In the Navy and Marine Corps, all personnel routinely vary their activity and must wear clothing appropriate for the activity they expect to engage in. How "hot" or "cold" the weather is plays an important part in both operational and training activities, and is especially important in physical readiness training. The temperature is also a factor in off-duty recreational activities. Ashore and aboard ship, weather office observers are routinely asked for various readings used as indicators for the effects of temperature on the human body. In this section, we discuss heat stress and the effects of cold on the human body, as well as the values and indicators operational planners use to avoid exposing personnel to these hazards.

HEAT STRESS

Heat stress is the effect of excessive heat on the body, and the inability of the body to get rid of excess heat fast enough to maintain an internal temperature balance. Sweating is a sign that the body is functioning normally to maintain its heat level. Now let's consider two types of heat stress: heat exhaustion and heat stroke.

Signs of heat exhaustion include profuse sweating with a pale skin color, drowsiness, headache, nausea, vision disturbances, or muscular cramps. Heat exhaustion is a dangerous condition and should be promptly treated. Heat stroke is indicated by a lack of sweating with a hot, dry, red skin, dizziness, restlessness, confusion, or unconsciousness. Heat stroke is a potentially fatal condition requiring immediate medical assistance.

Once a body has been heat stressed, the body's tolerance to heat decreases to a certain degree. Since heat stress will result in permanent physiological changes and may result in death, heat stress should be avoided. Two heat-stress-related indicators, relative humidity and the General Heat Stress Index (GHSI) are routinely computed by weather observers to serve as guidelines for exposure to high heat situations. An additional indicator, the wet-bulb globe temperature, is frequently used as a heat stress indicator in certain situations, but is not routinely computed by weather observers.

Relative Humidity

Relative humidity, commonly abbreviated "RH," is the ratio of how much water vapor is in the air compared to the amount of water vapor, at the current temperature and pressure, that the air can possibly hold, expressed as a percentage. Without adding water vapor to or extracting it from the air, the relative humidity will fall as the temperature rises during the day; and as the temperature falls at night, the relative humidity will rise. The measurements that provide us with the value of water vapor the air can possibly hold are the observed air temperature and the observed pressure. The measurement that yields a value of water vapor actually held by the air is the dew-point temperature, which is calculated from the dry- and wet-bulb temperatures.

Relative humidity is also the most requested indicator of heat effects on the body because it has been in use longer than any other, Just about everyone with an elementary education realizes that when relative humidity is high, the air feels hotter, and when the relative humidity is low, the air feels cooler. when the humidity is high, moisture does not evaporate efficiently from the skin, and the body temperature rises. But when the humidity is low, moisture on the skin evaporates rapidly and provides very efficient cooling of the body. Because of its widespread usage, relative humidity is routinely computed at many shore stations whenever the air temperature and wet-bulb temperatures are measured.

While the effects of moisture in the air affect how people react to temperature by altering the evaporation rate of moisture on the skin, the effects of wind may also alter the evaporation rate of moisture from the skin and affect the temperature of the human body.

General Heat Stress Index

The *General Heat Stress Index* (GHSI), also referred to as *the apparent temperature,* is a measure of how hot the air "feels" to an average person based on the temperature and the humidity. It does not take into account direct sunshine, wind, or the type of clothing a person is wearing. The GHSI value is the "apparent temperature" in National Weather Service public forecasts. The GHSI may be computed from the relative humidity and the air temperature by using figure 1-38.

As an example, with an air temperature of 90°F and a relative humidity of 60%, read the apparent temperature at the intersection of the horizontal air temperature line and the vertical relative humidity line. In this case the GHSI or the apparent temperature is 100°F. Interpolate between the lines as necessary. While interpretation of what a given apparent temperature feels like may vary from person to person, the differences among various apparent temperatures are objective and based on physiological research.

The General Heat Stress Index uses four categories to relate "apparent temperature" to the probable occurrence of heat-stress-related injury as follows:

- Apparent Temperature 130°F and up—Category I, EXTREME DANGER—Heatstroke imminent

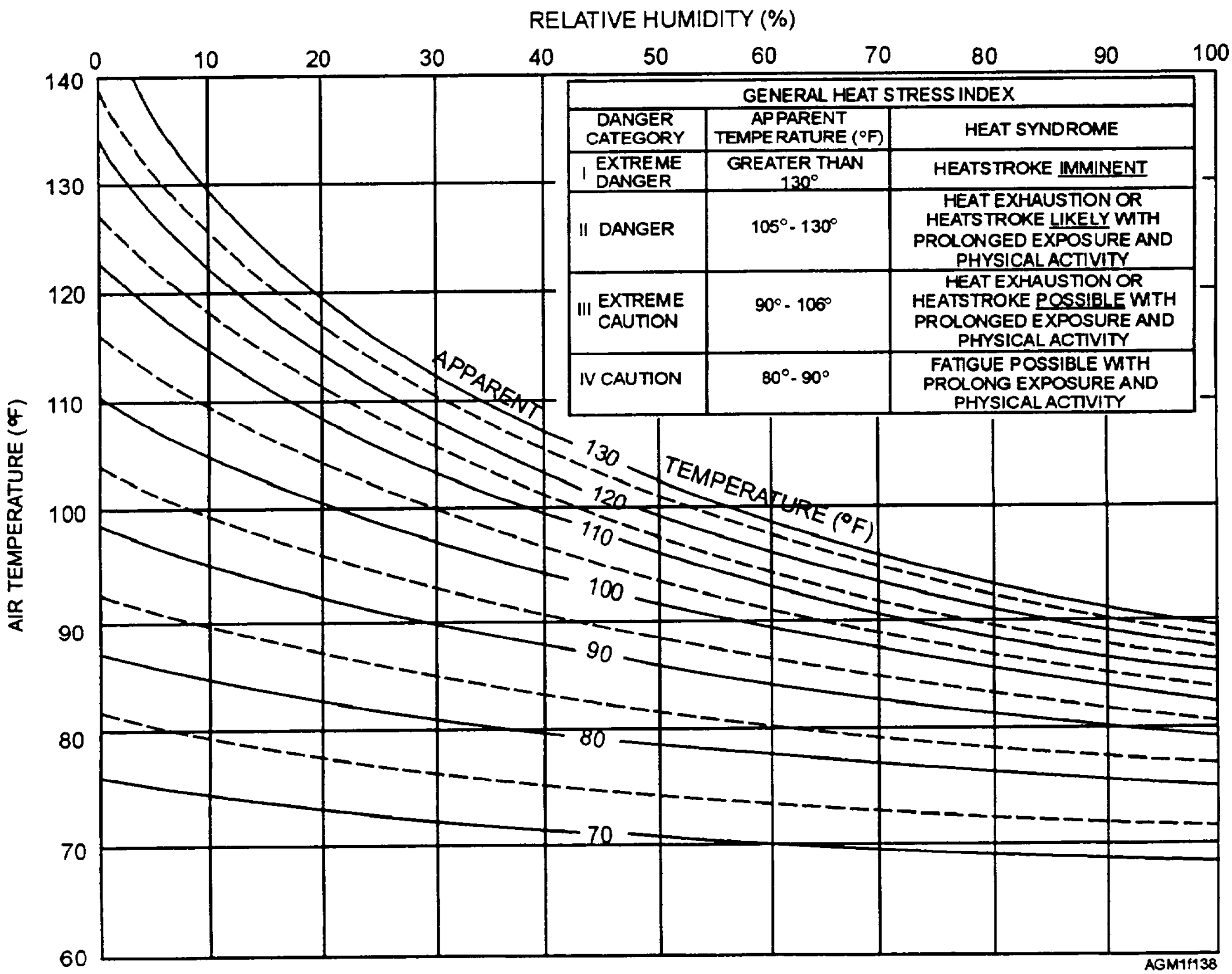

Figure 1-38.—General Heat Stress Index nomogram.

- Apparent Temperature 105°F to 130°F—Category II, DANGER—Heat exhaustion or heatstroke likely with prolonged exposure and physical activity
- Apparent Temperature 90° to 105°F—Category III, EXTREME CAUTION—Heat exhaustion or heatstroke possible with prolonged exposure and physical activity
- Apparent Temperature 80°F to 90°F—Category IV, CAUTION—Fatigue possible with prolonged exposure and physical activity

Since this index is based on the dry-bulb temperature, which by definition and practice is a shielded (in the shade) temperature, the presence of direct sunlight increases the danger.

Wet-bulb Globe Temperature Index

The *Wet-bulb Globe Temperature Index* is a heat stress indicator that considers the effects of temperature, humidity, and radiant energy. The required inputs for the index are measured by a wet-bulb globe temperature meter. The standard wet-bulb globe temperature meter in use by the Navy, called the "Navy Heat Stress Meter," gives a digital readout of dry- and wet-bulb temperatures and globe temperature, and computes a wet-bulb globe temperature (WBGT) index. Although similar to an electric psychrometer in that it has shielded, fan-ventilated dry- and wet-bulb thermometers, this device also has a globe temperature meter (a flat-black metal sphere that measures radiant energy).

Aboard ship, medical Corpsmen usually monitor WBGT readings. Chapter B2 of *the Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat,* OPNAVINST 5100.19, provides additional information on the shipboard heat stress control program. Since about 1980, the WBGT index has been gaining in usage as a regulatory guide for outdoor work situations; operational activities; and general training, such as field exercises, marching, and physical training. The WBGT index is used in conjunction with a Physiological Heat Exposure Limits (PHEL) chart to determine maximum exposure time for personnel working in high-heat interior environments. When applied to outdoor functions in hot climates, the PHEL charts are used to set activity limits, but a simplified guideline based strictly on the WBGT index is available for certain applications. When used in an outdoor environment, the WBGT index is the only index that compensates for the heating caused by direct or reflected sunshine. A variation of the computation, although not routinely used, also compensates for the cooling effect of the wind.

Various color codes are used outdoors to indicate the varying danger levels of heat stress. Some commands fly appropriate color-coded flags to indicate the heat-stress danger level. WBGT index readings less than 82°F generally mean little threat of heat stress, while readings between 82°F and 89.9°F indicate increasing danger levels. OPNAVMST 6110.1, *Physical Readiness Program,* recommends no physical readiness testing or training be done if the WBGT index is ≥85°F. WBGT index readings ≥90°F indicate a great heat-stress danger, and all strenuous outdoor activity should be avoided. The "danger" level is decreased to ≥80°F when heavy clothing, NBC gear, or body armor is worn. The WBGT index is calculated by the formula

$$W = 0.7WB + 0.2GT + 0.1DB,$$

where

W = the WBGT index, in degrees Fahrenheit;

WB = the wet-bulb temperature (°F);

GT = the globe temperature (°F); and

DB = the dry-bulb temperature (°F).

Additional information on WBGT index readings, PHEL charts, heat-stress dangers, and danger-level color codes may be found in in NAVMED P-5010-3, *Manual* of *Preventative Medicine.*

EFFECTS OF COLD

Just as the temperature alone is not a reliable indicator for how hot a person feels, the temperature of the air is not always a reliable indicator of how cold a person feels. Increased wind speeds may increase the rate of evaporation of moisture from exposed skin areas. This not only will make a person "feel" cooler, but will actually lower the skin temperature, and consequently, body temperature. While the type of clothing a person wears can provide protection from the chilling effects of the wind, the person's state of health and metabolism may affect his or her ability to produce heat. These factors all affect how cold a person will feel. Generally, coldness is related to the actual lowering of internal body temperature by the loss of heat from exposed flesh.

The two primary dangers to people exposed to the cold are frostbite and hypothermia. *Frostbite* is the freezing of the skin, which damages the skin and underlying flesh. *Hypothermia* is the lowering of the internal body temperature due to prolonged exposure to cold air or immersion in cold water.

Frostbite may cause only localized tissue death; but hypothermia, if not reversed, will kill people. When the normal internal body temperature falls below 98.6°F, shivering begins. As internal body temperature approaches 95°F, the body will usually be in uncontrolled, violent-shivering spasms. Lower temperatures cause loss of mental processes, a cessation of shivering, muscle rigidity, unconsciousness, and then death as the body cools below 80°F.

Wind Chill Equivalent Temperature

The wind chill equivalent temperature (also called the *wind chill index,* the *wind chill factor,* or just plain *wind chill*), is the temperature required under no-wind conditions that will equal the cooling effect of the air (the actual air temperature) and the wind on an average size, nude person in the shade. Moisture content of the air, visible moisture on the skin or clothing, presence of sunshine, clothing, and physical activity are not considered.

Wind chill equivalent temperature is found by use of the wind chill nomogram (fig. 1-39). The vertical lines on the nomogram indicate air temperature, in degrees Fahrenheit; the horizontal lines indicate wind speed, in knots; and the curved lines indicate wind chill equivalent temperature. From the intersection of the air temperature line and the wind speed line, follow the curved line downward to the left to read the wind chill. The dashed lines on the nomogram illustrate an example of a wind chill determination with an air temperature of 20°F and a wind speed of 29 knots: the resultant wind chill is -10°F. Interpolate between the lines as necessary. Other tables are used to determine wind chill, but unfortunately, most require wind speed in miles per hour rather than the standard measurement of knots used by the Navy and Marine Corps.

Weather observers should avoid making any recommendations for when and how long people may work outdoors during cold weather. Frostbite and hypothermia depend on the clothing people wear, their level of activity, and the length of time exposed to the cold.

Seawater Immersion Survivability

When a person is immersed in water, the major factor on the length of time the person can survive is the seawater temperature. Some other factors are the sea condition (height and length of the waves), the person's ability to swim, the person's physical condition, and the person's clothing.

When immersed in water, the human body loses heat to the water by conduction. If a person is immersed long enough, internal body temperature falls and unconsciousness or death occurs (fig. l-40). The survivability assumes that the sea condition is not a factor, and that the person is an average swimmer, in average physical condition, with no special clothing.

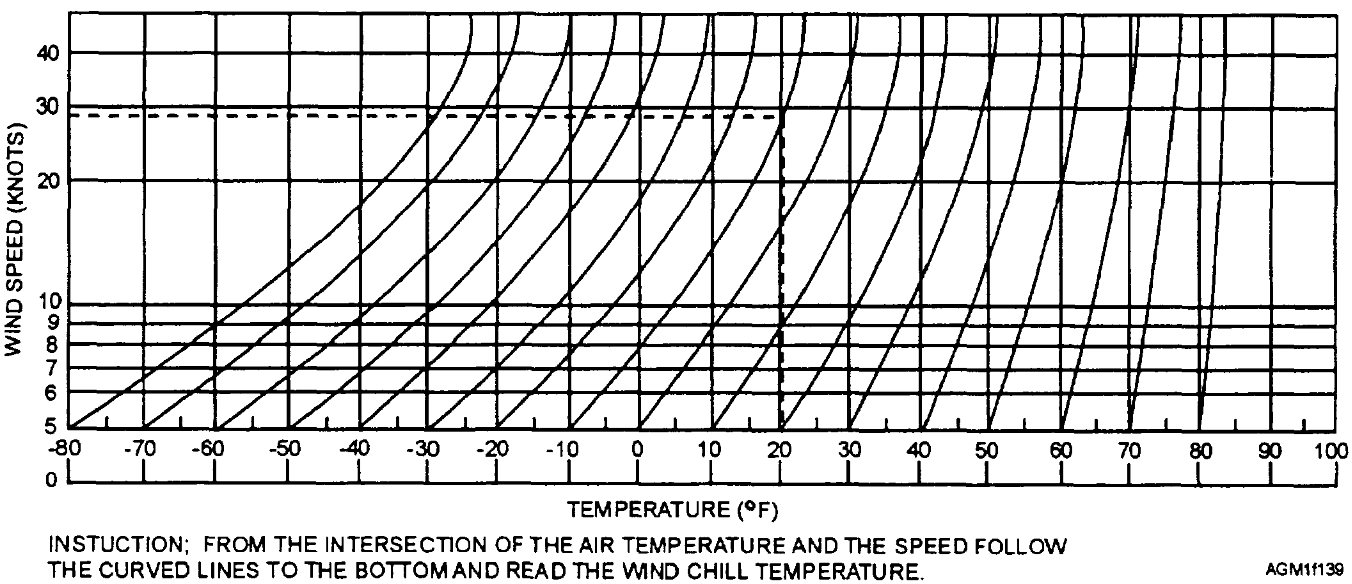

Figure 1-39.—Wind Chill Equivalent Temperature nomogram.

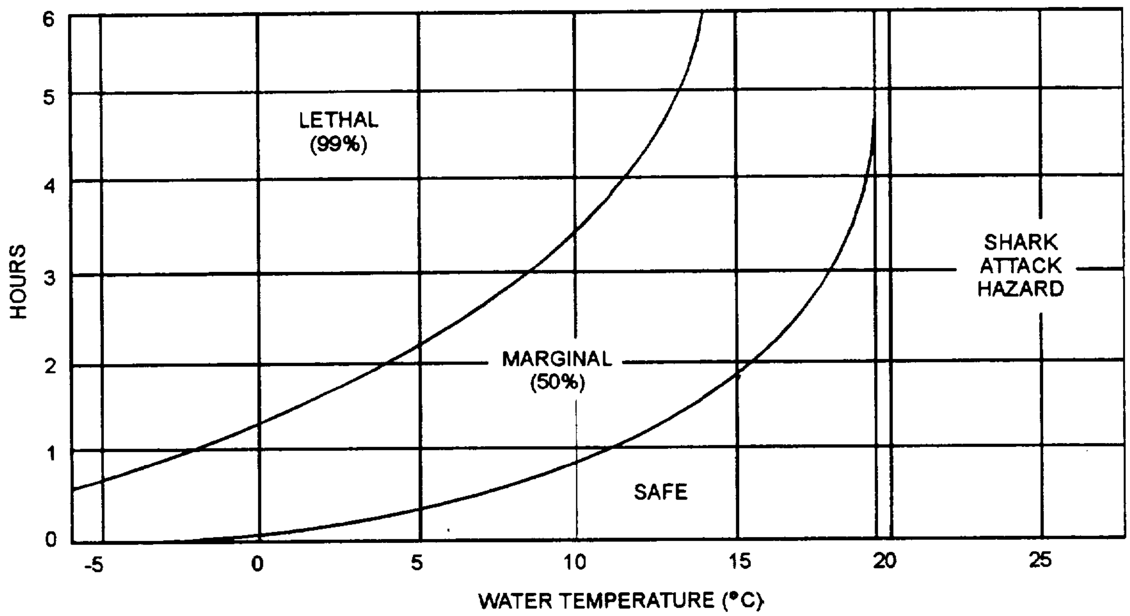

Figure 1-40.—Survivability of a person in water.

Anti-immersion suits are worn by aircrew personnel to retain body heat if the aircrew must ditch in the water. Unfortunately, anti-immersion gear is bulky and hot, and aircrews prefer not to wear the gear. When environmental conditions indicate usage is required, shipboard Aerographers routinely include in flight weather briefings the recommendation that aircrews use anti-immersion suits. This recommendation should also be included in shore-station briefings for over-water flights. Navy and Marine Corps observers usually provide the necessary information to the briefer, based on their observations of the environmental conditions.

Guidance for anti-immersion suit usage by aircrews is given in OPNAVTNST 3710.7, *NATOPS General Flight and Operating Instructions.* Anti-immersion suits or pressure suits with thermal undergarments must be worn when the coldest water temperature in the mission area is ≥50°F or if the coldest wind chill equivalent temperature on the (water) surface during the mission is ≤32°F. When the water temperature is >50°F but ≤60°F, antiexposure undergarments must be worn, but the determination to wear anti-immersion suits is made by the commanding officer. His or her determination should be based on the length of time required to respond with rescue assets to a ditch site, ranging from 1 hour at 50°F to 3 hours at 60°F. With water temperatures above 60°F, anti-immersion gear is not required.

Navy and Marine Corps weather observers routinely provide various values and indicators that are used to gauge the effects of hot and cold environments on personnel. These values are computed from observed measurements made during surface weather observations. All observers should be aware of the effects of heat and cold on the human body, and should be able to calculate the various indicators upon request. Weather affects the performance of equipment as well as personnel. In the next section, we consider aircraft performance in changing weather conditions.

REVIEW QUESTIONS

Q86. What term describes the inability of *the body to get rid* of *excess heat fast enough to maintain an internal temperature balance?*

Q87. Define the term "relative humidity."

Q88. Given an air temperature of 90°F and a relative humidity of *65%, what is the apparent temperature?*

Q89. What effects does the Wet-bulb Globe Temperature index (WBGT) take into consideration?

Q90. What is meant by the term "wind chill factor"?

Q91. What is the survival chance given a seawater temperature of *15°C and an immersion time* of 3 *hours.*

COMPUTATION OF AIRCRAFT PERFORMANCE INDICATORS FROM OBSERVED DATA

LEARNING OBJECTIVES: Identify three aircraft performance indicators computed from observed data. Define the terms pressure altitude, density altitude, and specific humidity. Describe the procedure used to compute pressure altitude and density altitude. Identify the procedure used to find specific humidity.

Air density and water vapor content of the air have an important effect upon aircraft engine performance and takeoff characteristics. In this section, we describe some of these effects and how they are computed. The three most common elements an Aerographer's Mate must furnish information on are pressure altitude, density altitude, and specific humidity. All ofthesemay be determined by using a Density Altitude Computer, discussed in chapter 2, while pressure altitude and density altitude can be easily obtained from ASOS. Pressure altitude and density altitude are given in feet; while specific humidity is provided in grams per gram or in pounds per pound. Now let's look at pressure altitude.

PRESSURE ALTITUDE

Pressure altitude is defined as the altitude of a given atmospheric pressure in the standard atmosphere. The pressure altitude of a given pressure is usually a fictitious altitude, since it is rarely equal to true altitude. Pressure altitude is equal to true altitude only when pressure at sea level (or the flight-level pressure) corresponds to the pressure of the U.S. Standard Atmosphere. Pressure altitude higher than the actual altitude indicates the air is less dense than normal, and the aircraft may not be able to carry a full (standard) cargo load. Pressure altitude lower than the actual altitude means the air is more dense than normal, and the aircraft may be able to takeoff successfully with a larger cargo load.

Aircraft altimeters are constructed for the pressure-height relationship that exists in the standard atmosphere. Therefore, when the altimeter is set to standard sea-level pressure (29.92 inches of mercury), it indicates pressure altitude and not true altitude. Flight levels-an indicated altitude based on an altimeter setting of 29.92 inches-rather than true altitudes, are flown above 18,000 feet in the United States, and on over-water flights more than 100 miles offshore. The quickest method for approximating the pressure altitude is by using the Pressure Reduction Computer (CP-402/UM), covered in chapter 2. Detailed instructions are listed on the computer. For your own station, you simply dial in the current station pressure and read the pressure altitude on the scale. The solution is more complex when converting forecast altimeter settings to pressure altitude, but the pressure reduction computer may still be used. On occasion, you may find yourself in a situation where this device is not available. Two alternate methods follow that will enable you to calculate approximations of the pressure altitude. Pressure altitude varies directly with the change in pressure multiplied by a complex variable. The variable amount takes into account temperature and station elevation. Both methods simplify the equation but still give fairly close pressure altitude approximations.

The first method uses a set of precalculated pressure altitudes based on pressure differences from standard pressure. These are listed in table 1-5.

Using the table, you may find the pressure altitude value corresponding to your current or forecast altimeter setting or the current or forecast altimeter setting for any other station. This value must be added to your station elevation or the other station's elevation to find the pressure altitude. For example, if your altimeter setting is 29.41 inches and your station elevation is 1,500 feet, you would enter the left side of the table with "29.4" and find the intersection of the column under "0.01" to find 476 feet. Add 476 feet to your station elevation, 1,500 feet, to find the pressure altitude 1,976 feet.

You may also use the table to find pressure altitude by using station pressure. Station elevation should NOT be added to the value when using station pressure.

The second method is useful when you do not have ready access to the table. To calculate pressure altitude, use the formula

$$PA = H_A + PAV,$$

where

PA = pressure altitude,

H_A = station elevation, and

$PA\ V$ = pressure altitude variation approximation (or 29.92 minus the current altimeter setting times 1,000).

Table 1-5.—Pressure Altitude Values

Hundredths →	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
PRESSURE inches & ↓tenths↓	**PRESSURE ALTITUDE (FEET)**									
28.0	1824	1814	1805	1795	1785	1776	1766	1756	1746	1737
28.1	1727	1717	1707	1698	1688	1678	1668	1659	1649	1639
28.2	1630	1620	1610	1601	1591	1581	1572	1562	1552	1542
28.3	1533	1523	1513	1504	1494	1484	1475	1465	1456	1446
28.4	1436	1427	1417	1407	1398	1388	1378	1369	1359	1350
28.5	1340	1330	1321	1311	1302	1292	1282	1273	1263	1254
28.6	1244	1234	1225	1215	1206	1196	1186	1177	1167	1138
28.7	1148	1139	1129	1120	1110	1100	1091	1081	1072	1062
28.8	1053	1043	1034	1024	1015	1005	995	986	976	967
28.9	957	948	938	929	919	910	900	891	881	872
29.0	863	853	844	834	825	815	806	796	787	777
29.1	768	758	749	739	730	721	711	702	692	683
29.2	673	664	655	645	636	626	617	607	598	589
29.3	579	570	560	551	542	532	523	514	504	495
29.4	485	476	467	457	448	439	429	420	410	401
29.5	392	382	373	364	354	345	336	326	318	308
29.6	298	289	280	270	261	252	242	233	224	215
29.7	205	196	187	177	168	159	149	140	131	122
29.8	112	103	94	85	75	66	57	47	38	29
29.9	20	10	+1	-8	-17	-26	-36	-45	-54	-63
30.0	-73	-82	-91	-100	-100	-119	-128	-137	-146	-156
30.1	-165	-174	-183	-192	-202	-211	-220	-229	-238	-248
30.2	-257	-266	-275	-284	-293	-303	-312	-321	-330	-339
30.3	-348	-358	-367	-376	-385	-394	-403	-412	-421	-431
30.4	-440	-449	-458	-467	-476	-485	-494	-504	-513	-522
30.5	-531	-540	-549	-558	-567	-576	-585	-594	-604	-613
30.6	-622	-631	-640	-649	-658	-667	-676	-685	-694	-703
30.7	-712	-721	-730	-740	-749	-758	-767	-776	-785	-794
30.8	-803	-812	-821	-830	-839	-848	-857	-866	-875	-884
30.9	-893	-902	-911	-920	-929	-938	-947	-956	-965	-974
31.0	-983	-992	-1001	-1010	-1019	-1028	-1037	-1046	-1055	-1064

INPUT STATION PRESSURE: READ PRESSURE ALTITUDE DIRECTLY FROM TABLE.
INPUT ALTIMETER SETTING: READ VALUE FROM TABLE AND ADD STATION ELEVATION TO FIND PRESSURE ALTITUDE.

For example, using the formula for the same case we just calculated with the table, we find the following:

$$PA = H_A + PAV$$

$$PA = 1{,}500 + 1{,}000(29.92 - 29.41)$$

$$PA = 1{,}500 + 510$$

$$PA = 2{,}010 \text{ feet}$$

By comparison, you can see that this value is 34 feet higher than we found by using the table, but it is a close enough approximation when nothing else is available. And, it may be done quickly in your head. With the pressure reduction computer, the same case yields a pressure altitude of 1,979 feet.

Pilots of aircraft, especially rotary wing aircraft, frequently ask for maximum pressure altitude for takeoff and for all destinations. This is calculated using the lowest expected altimeter setting (QNH) for the destination. The forecaster may have to interpret the other station's forecast to determine if the forecast QNH will be valid during the time the aircraft will be in the vicinity. Many rotary wing aircraft have a table in their aircraft technical data that is entered using maximum pressure altitude and maximum temperature to find the maximum permissible load that can be carried. Maximum pressure altitude may be used by the pilot in lieu of density altitude.

DENSITY ALTITUDE

Density altitude is defined as the altitude at which a given air density is found in the standard atmosphere. For a given altitude, density altitude changes with changes in pressure, air temperature, and humidity. An increase in pressure increases air density, so it decreases density altitude. An increase in temperature decreases air density, so it increases density altitude. An increase in humidity decreases air density, so itincreases density altitude. Changes in pressure and temperature have the greatest effect on density altitude, and changes in humidity have the least effect.

If, for example, the pressure at Cheyenne, Wyoming, (elevation 6,140 feet) is equal to the pressure of the standard atmosphere at that elevation, and the temperature is 101°F, the density would be the same as that found at 10,000 feet. Therefore, the air is less dense than normal, and an aircraft on takeoff (at approximately constant weight and power setting) will take longer to get airborne. Air density also affects airspeed. True airspeed and indicated airspeed are equal only when density altitude is zero. True airspeed exceeds indicated airspeed when density altitude increases.

No instrument is available to measure density altitude directly. It must be computed from the pressure (for takeoff, station pressure) and the virtual temperature at the particular altitude under consideration. This may be accomplished by using the Density Altitude Computer (CP-718/UM) or from Table 69, Density Altitude Diagram, of *Smithsonian Meteorological Tables*, NA-50-lB-521. Remember, virtual temperature is used in the computation of density altitude.

The quickest method of calculating density altitude is to use the Density Altitude Computer (CP-718/UM), discussed in chapter 2. Density altitude must be computed from the pressure (for takeoff, station pressure) and the virtual temperature at the particular altitude under consideration. Specific instructions are printed on the device. Density altitude results from the computer may be estimated to the nearest 10 feet between the marked increments of 100 feet. If you are in a situation where you do not have a density altitude computer or the *Smithsonian Meteorological Tables* available, you may ignore the humidity value and calculate density altitude by the formula

$$DA = PA + (120\ V_t),$$

where

DA = density altitude,

PA = pressure altitude at the level you desire density altitude,

120 = a temperature constant (120 feet per 1°C), and

V_t = actual temperature minus standard temperature at the level of the pressure altitude.

For example, let's say the surface temperature is 30°C and your pressure altitude is 2,010 feet. Look at table 1-6 and find the standard temperature corresponding to 2,000 feet. You should find 11°C. Plug these values into the formula to find the following:

$$DA = PA + (120\ V_t)$$

$$DA = 2{,}010 \text{ feet} + [120(3°C - 11°C)]$$

$$DA = 2{,}010 + 120(19)$$

$$DA = 2{,}010 + 2{,}280$$

$$DA = 4{,}290 \text{ feet}$$

Table 1-6.—U.S. Standard Atmosphere Heights and Temperatures

HEIGHTS TO STANDARD PRESSURE AND TEMPERATURE

Altitude, feet	Pressure, hPa	Pressure, inches	Temperature, °C	Temperature, °F	Altitude, feet	Pressure, hPa	Pressure, inches	Temperature, °C	Temperature, °F
0	1013.2	29.92	15.0	59.0	26,000	359.9	10.63	-36.5	-33.7
1,000	977.2	28.86	13.0	55.4	27,000	344.3	10.17	-38.5	-37.3
2,000	942.1	27.82	11.0	51.9	28,000	329.3	9.72	-40.5	-40.9
3,000	908.1	26.82	9.0	48.3	29,000	3 14.8	9.30	-42.5	-44.4
4,000	875.1	25.84	7.1	44.7	30,000	300.9	8.89	-44.4	-48.0
5,000	843.1	24.90	5.1	41.2	31,000	287.4	8.49	-46.4	-51.6
6,000	812.0	23.98	3.1	37.6	32,000	274.5	8.11	-48.4	-55.1
7,000	781.8	23.09	1.1	34.0	33,000	262.0	7.74	-50.4	-58.7
8,000	752.6	22.22	-0.8	30.5	34,000	250.0	7.38	-52.4	-62.2
9,000	724.3	21.39	-2.8	26.9	35,000	238.4	7.04	-54.3	-65.8
10,000	696.8	20.58	-4.8	23.3	36,000	227.3	6.71	-56.3	-69.4
11,000	670.2	19.79	-6.8	19.8	37,000	216.6	6.40	-56.5	-69.7
12,000	644.4	19.03	-8.8	16.2	38,000	206.5	6.10	Constant to	
13,000	619.4	18.29	-10.8	12.6	39,000	196.8	5.81	65,500 feet	
14,000	595.2	17.58	-12.7	9.1	40,000	187.5	5.54		
15,000	571.8	16.89	-14.7	5.5	41,000	178.7	5.28		
16,000	549.2	16.22	-16.7	1.9	42,000	170.4	5.04		
17,000	427.2	15.57	-18.7	-1.6	43,000	162.4	4.79		
18,000	506.0	14.94	-29.7	-5.2	44,000	154.7	4.57		
19,000	484.5	14.34	-22.6	-8.8	45,000	147.5	4.35		
20,000	465.6	13.75	-24.6	-12.3	46,000	140.6	4.15		
21,000	446.4	13.18	-26.6	-15.9	47,000	134.0	3.96		
22,000	427.9	12.64	-28.6	-19.5	48,000	127.7	3.77		
23,000	410.0	12.11	-30.6	-23.9	49,000	121.7	3.59		
24,000	392.7	11.60	-32.5	-26.6	50,000	116.0	3.42		
25,000	376.0	11.10	-34.5	-30.2					

STANDARD PRESSURE SURFACES

Pressure surface, hPa	Height, feet	Height, meters	Temperature °C	Temperature °F	Pressure surface, hPa	Height, feet	Height, meters	Temperature, °C	Temperature, °F
1000	364	111	14.2	57.8	200	38,662	11,784	-56.7	-70.1
925	2,512	766	10.0	50.0	150	44,647	13,608	-56.7	-70.1
850	4,781	1,457	5.5	41.9	100	53,083	16,180	-56.7	-70.1
700	9,882	3,012	-4.7	23.5	70	60,504	18,442	-56.7	-70.1
500	18,289	5,574	-21.3	-6.3	50	67,507	20,576	-55.8	-68.4
400	23,574	7,185	-31.7	-25.1	30	78,244	23,849	-52.7	-62.9
300	30,065	9,164	-44.7	-48.5	20	86,881	26,481	-49.9	-57.8
250	33,999	10,363	-52.4	-62.3	10	101,885	31,055	-45.4	-49.7

For an acceptable result with slightly less precision, you may use the density altitude diagram (fig. 1-41) to obtain density altitude to the nearest 200 feet. This diagram also ignores the effect of humidity on density altitude. Enter the bottom of the diagram with your air temperature and proceed vertically to the intersection of the pressure altitude line, then horizontally to the left side of the diagram to find the density altitude. The light dashed line shows an example using 22°C and a pressure altitude of 10 feet, resulting in a density altitude of about 1,000 feet.

You may interpolate for more precise values, but this precision isn't often necessary for most density altitude calculations. (A quick method of determining standard temperatures in degrees Celsius for all levels up to 35,000 feet is to double the altitude in thousands of feet, subtract 15, and change the sign.)

SPECIFIC HUMIDITY

Specific humidity is the mass of water vapor present in a unit mass of air. Where temperatures are high and rainfall is excessive, the specific humidity of the air reaches high proportions. Accurate information is required to determine the proper amount of horsepower needed for the takeoff roll.

Fog and humidity affect the performance of aircraft. During takeoff, two things are done to compensate for their effect on takeoff performance. First, since humid air is less dense than dry air, the allowable takeoff gross weight is generally reduced for operations in areas that are consistently humid. Second, because power output is decreased by humidity, pilots must compensate for the power loss. Your main responsibility as an Aerographer's Mate is to ensure that the pilot has accurate information. Pilots may request humidity values as either relative humidity (discussed in the previous section) or specific humidity.

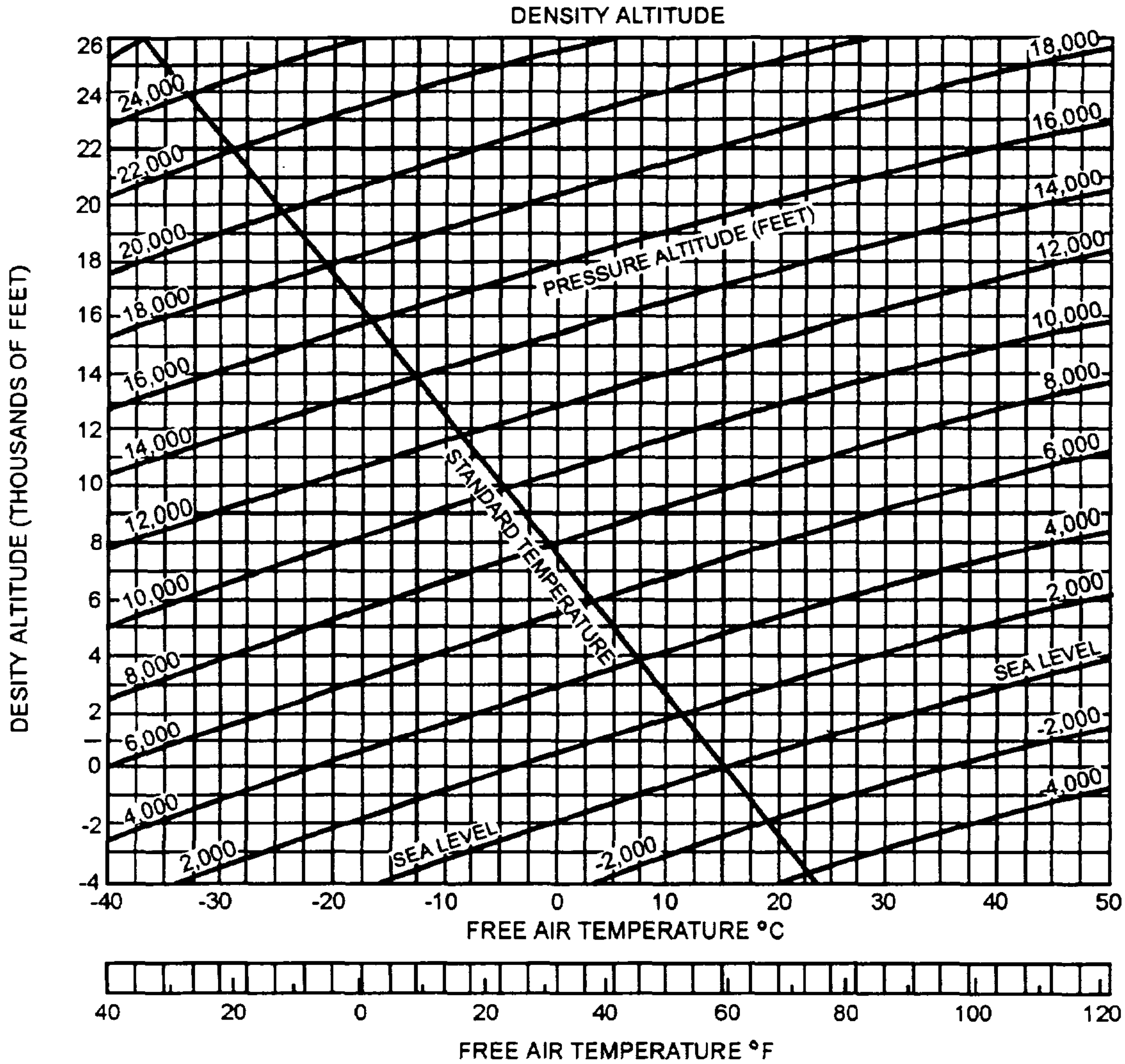

Figure 1-41.—Density altitude diagram.

Specific humidity can be determined from the CP-718/UM density altitude computer following instructions printed on the computer. The air temperature, dew-point temperature, and pressure from the observation are used as arguments.

Proper performance of aircraft engines and the lift produced by the aircraft's wings depend on the density of the air. Air density is affected by pressure, temperature, and water content of the air. Calculated values of pressure altitude, density altitude, and specific humidity are routinely done to provide pilots with specific quantities on which they may base computations for the thrust, lift, and maximum loads for their aircraft.

REVIEW QUESTIONS

Q92. What does a pressure altitude lower than the actual altitude mean?

Q93. What happens to density altitude when the air temperature increases?

Q94. How may density altitude be calculated?

Q95. How does humidity affect air density?

SUMMARY

In this chapter, we have discussed the terms and procedures used when evaluating and measuring surface weather elements, and some of the routinely computed values and indicators associated with surface weather observations. The material has been presented in a manner that, we hope, will guide you to a basic understanding of the subject of "surface weather observations." Additional study of the publications and manuals referenced in the text, especially NAVMETOCCOMINST 3141.2, *Surface METAR Observations User's Manual,* and NAVMETOCCOMINST 3144.1, *United States Navy Manual for Ship's Surface Weather Observations*, will be necessary for a thorough understanding of the subject.

ANSWERS TO REVIEW QUESTIONS

A1. *NAVMETOCCOMINST 3141.2, Surface METAR Observations User's Manual, and NAVMETOCCOMINST 3144.1, United States Navy Manual for Ship's Surface Weather Observations.*

A2. *Fahrenheit, Celsius, and Kelvin.*

A3. *15° of longitude.*

A4. *Coordinated Universal Time.*

A5. *Pressure.*

A6. *27.*

A7. *Cumuliform, stratiform, cirriform.*

A8. *Stratiform.*

A9. *Mechanical lift associated with physical barriers forcing air aloft, convective lift associated with surface heating, convergence resulting from a "piling"of air, and vorticity associated with the rotational motion of molecules in the air and the spinning of the earth.*

A10. *6,500 to 23,000 feet.*

A11. *Variety identifies the specific appearance of the arrangement of elements within a cloud layer, the thickness of the layer, or the presence of multiple layers.*

A12. *Cumulonimbus.*

A13. *The amount of moisture near the surface.*

A14. *If the height of the cumulus congestus cloud appears to be twice the width of the base, it should be classified as towering cumulus.*

A15. *An anvil top.*

A16. *Low-level wind shear and microbursts.*

A17. *The right rear quadrant with respect to CB movement.*

A18. *Nimbostratus.*

A19. *When precipitation begins or when bases drop to less than 6,500 feet.*

A20. *Approaching frontal systems with conditions favorable for thunderstorm activity.*

A21. *Ice crystals.*

A22. *Formed when strong winds moving across mountains set up a wavelike action in the winds downstream from the mountain. The upward moving air in the waves, if moist, is brought to saturation as it rises.*

A23. *Formed when moist air is forced upward by a mountain top and dissipates on the leeward side of the mountain as the moving air descends.*

A24. *In eighths of the sky.*

A25. *Clouds and/or obscuring phenomena aloft either continuous or composed of detached elements that have bases at approximately the same level.*

A26. *The lowest layer that blocks 5/8 ormoreofthe celestial dome from beingseen.*

A27. *Any collection of atmospheric phenomena dense enough to obscure even the portion of the sky directly overhead.*

A28. *Sky cover at any level is equal to the amount the sky cover of the lowest layer plus the additional sky cover present at all successively higher layers (up to and including the layer being considered).*

A29. *12,000 feet.*

A30. *7,500 feet.*

A31. *Prevailing visibility, sector visibility, differing level (or tower) visibility, and runway visual range.*

A32. *The greatest distance that known objects can be seen and identified throughout half or more of the horizon circle.*

A33. *Combat Information Center (CIC).*

A34. *When it differs from the prevailing visibility, and either prevailing visibility or sector visibility is less than 3 miles.*

A35. *When the prevailing visibility is 4 miles or less.*

A36. *Haze.*

A37. *In desert regions on calm, hot, clear afternoons.*

A38. *Blowing sand that reduces visibility to less than 5/16 of a mile.*

A39. *Water vapor bypasses the liquid state and goes directly from a gas to a solid.*

A40. *Moisture, hygroscopic nuclei, and cooling.*

A41. *Four Celsius degrees or less.*

A42. *Advection fog.*

A43. A fog condition that reduces prevailing visibility to between 5/8 mile and 6 miles.

A44. Frost occurs when radiational cooling lowers the temperature of an object below the freezing level and ice crystals form through sublimation.

A45. Super-cooled liquid.

A46. The slow rate of fall and droplet size (less than 0.02 inch).

A47. Ice pellets.

A48. Moderate.

A49. Lightning cloud-to-air.

A50. When the first thunder is heard, or when overhead lightning is observed, and the local noise level is high enough as might prevent the observer from hearing thunder.

A51. 10 hectopascals.

A52. The pressure correction applied to station pressure based on the difference in height of the barometer and the runway or station elevation.

A53. 1.62 hectopascals or .045 inches of mercury.

A54. It is a pressure value used by aircraft to allow correct determinations of height above mean sea level.

A55. A barograph trace or the actual recorded pressures during the period.

A56. The lowest temperature to which an object may be cooled by the process of evaporation.

A57. Condensation and/or precipitation.

A58. 12.5°F.

A59. The temperature, below freezing, that a parcel of air must be cooled to in order to reach saturation.

A60. Bucket method, bathythermograph method, and seawater injection method.

A61. True North is in reference to the geographic North Pole while Magnetic North is in reference to the magnetic North Pole.

A62. 090°

A63. Using the CP-264/U true wind computer, a maneuvering board, or an aerological plotting chart.

A64. By using the arithmetic or graphical average during the 2-minute observation period.

A65. It would be less than the actual wind speed.

A66. A rapid fluctuation in wind speed with a variation between peaks and lulls of 10 knots or more observed in the lo-minute period prior to the actual time of observation.

A67. A sudden increase in wind speed of 16 knots or more and the sustained increase must be 22 knots or more for at least 1 minute.

A68. The vertical distance from the crest to the trough of the wave.

A69. The wind speed, the length of time the wind has been blowing, and the size of the fetch area.

A70. 8 to 13 feet.

A71. The time it takes for a complete wave cycle to pass a given point.

A72. Wavedirection is the direction the majority of waves in a group are coming from.

A73. The average height of the highest 1/3 of all the waves present,

A 74. Swell waves are sea waves that have moved out of the area of formation and are more smooth and regular in appearance.

A75. By using the average height of all the swell waves present.

A76. 14°F.

A 77. The source of the ice accretion, the thickness of the ice, and a determination of the rate of accumulation or melt-off.

A 78. It is due to the salinity of seawater and the density changes in seawater caused by salinity. In addition, thefreezingofseawater is slowed because of waves, currents, and tides.

A 79. March.

A80. Sea ice that is frozen solidly to the shores of islands or land masses.

A81. Rafting ice indicates that the ice is closing rapidly.

A82. It normally drifts to the right (about 30°) of the wind direction.

A83. Antarctica and Greenland.

A84. The prevailing sea current at the icebergs submerged depth.

A85. NAVMETOCCOMINST 3144.1

A86. Heat stress.

A87. The ratio of how much water vapor is in the air compared to the amount of water vapor, at the current temperature andpressure, that the air can possibly hold.

A88. 105°F.

A89. Temperature, humidity, and radiant energy.

A90. The temperature required under no-wind conditions that will equal the cooling effect of the actual air temperature in conjunction with the wind.

A91. Marginal.

A92. The air is more dense than normal.

A93. It increases density altitude.

A94. By using the Density Altitude Computer (CP-718/UM), the Smithsonian Meteorological Tables, the Density Altitude Formula, or the Density Altitude Diagram.

A95. It decreases air density.